THE SCIENCE MASTERS' BOOK

PART I
PHYSICS

THE SCIENCE MASTERS' BOOK

PART I
PHYSICS

BEING EXPERIMENTS SELECTED FROM THE *SCHOOL SCIENCE REVIEW* BY A COMMITTEE OF THE SCIENCE MASTERS' ASSOCIATION

EDITED AND ARRANGED BY

G. H. J. ADLAM, M.A., B.Sc.

WITH THE ASSISTANCE OF

W. H. BARRETT (Harrow School), F. FAIRBROTHER (Cedars School), T. HARTLEY (Commonweal Secondary School, Swindon), O. H. LATTER (late Charterhouse), E. J. MOORE (Birmingham Central Technical College), G. N. PINGRIFF (Merchant Taylors' School), V. T. SAUNDERS (Uppingham), E. G. SAVAGE, H.M.I., A. VASSALL (Harrow School)

LONDON

JOHN MURRAY, ALBEMARLE STREET, W.

First Edition . . . 1931

PREFACE

SINCE the *School Science Review* was started in June 1919, notes on Apparatus and Experiments have been a fairly constant feature, and this book is the natural outcome. Besides contributions from members of the Science Masters' Association, many have been obtained, directly or indirectly, from University teachers—directly in the form of articles and notes to the *School Science Review*, indirectly in the form of demonstrations given at the Annual Meetings of the Association.

A great many of the notes are original, or believed to be original, though it is sometimes difficult, particularly in Natural Science, to be quite certain on that point. Many, however, whose names are put to the notes emphatically disclaim original authorship. The ideas have been acquired from forgotten sources, and no doubt many old ways of doing things have been here brought up again.

The book is necessarily a scrap-book, and it is inevitable that it must lack continuity. Another peculiarity incidental to this kind of compilation is the somewhat rapid transition, even within a single section, from work suitable for the Middle School to that of the Sixth Form and Scholarship candidates.

Scraps are not easy to arrange in such a way as to gain general approbation. Some expect to find all country churches together and all country inns; others prefer that they should appear topographically. A desirable feature in the arrangement of a miscellany is that the reader should be able to find his way about it easily, and, what is more, be able to retrace previous steps without much perplexity. Sub-headings have therefore been

freely used in the full list of titles that follows, and these pointers have been arranged in alphabetical order. This brings about some juxtapositions strange to formal science, but then, do not Fred Archer the jockey, Lord Armstrong the armament maker, and Matthew Arnold the poet, rub shoulders in the *Dictionary of National Biography*?

A large amount of space might have been saved by leaving out the "performance" guarantees, but these, it is hoped, will be helpful and encouraging, like "footprints on the sands of time."

The Chairman and Committee of the Science Masters' Association acknowledge with sincere gratitude all the help that they have received from members of the Association, from University teachers, and from others interested in the development of science teaching in schools.

G. H. J. A.

CITY OF LONDON SCHOOL,
E.C.4.

LIST OF TITLES

MECHANICS AND PROPERTIES OF MATTER

ACCELERATION

BOYLE'S LAW

DENSITY

ELASTICITY

FORCE

PRESSURE

ROTATION OF THE EARTH

SURFACE TENSION

VISCOSITY

WAVE MOTION

HEAT

CALORIMETRY

CHANGE OF STATE

CONVECTION

EXPANSION

MAXIMUM DENSITY

RADIATION

SPECIFIC HEAT RATIO

LIGHT

CAMERAS

COLOUR (see also DISPERSION and SPECTRUM)

DIFFRACTION

DISPERSION (see also COLOUR and SPECTRUM)

ECLIPSE OF THE SUN

FLUORESCENCE

INTERFERENCE

PHOTOMETRY

REFLECTION

REFRACTION

SCATTERING

SPECTRUM (see also COLOUR and DISPERSION)

SOUND

AUDIBILITY

DETECTORS

DIFFRACTION

DOPPLER EFFECT

INTERFERENCE

REFLECTION

RESONANCE

TRANSMISSION

VIBRATION IN PIPES

VIBRATION OF RODS

VIBRATION OF STRINGS

WAVE MACHINES

MAGNETISM

ELECTRO-MAGNETISM

MAGNETIC MEASUREMENTS

MAGNETOSTRICTION

MAGNETIC POLES

ELECTRICITY

ALTERNATING CURRENT

MOTOR

NEON LAMPS

MECHANICS AND PROPERTIES OF MATTER

ACCELERATION

1. TIMING A FALLING BODY

C. J. L. Wagstaff

THE apparatus shown in the diagram is designed to find by a direct experimental method the time a body takes to fall a specified distance. The result is accomplished by making the time of fall synchronise with a half-period of vibration of an adjustable pendulum. The falling body is dropped from an electromagnet (E.M.) when the energising circuit is broken by the pendulum passing through the middle position.

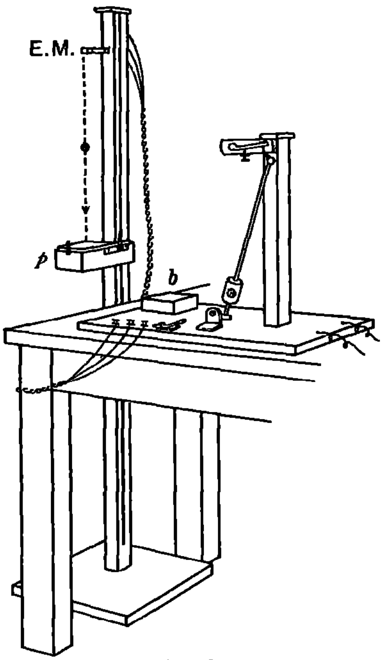


FIG. 1.

The body falls upon a platform, p, which moves up and down on a vertical standard. The impact of the body on the platform breaks momentarily one arc, y, of a second circuit, the other arc, x, of which passes through a connection governed by the pendulum and is broken each time

the pendulum passes the mid-position. These two arcs in parallel are joined in series with a bell, b, which sounds only when the currents in both the arcs are both broken.

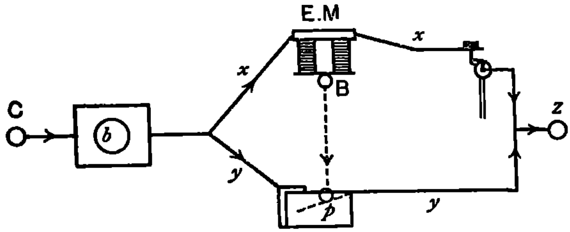


FIG. 2.

The body is thus released by the first passage of the pendulum through the mid-position ; if the body strikes

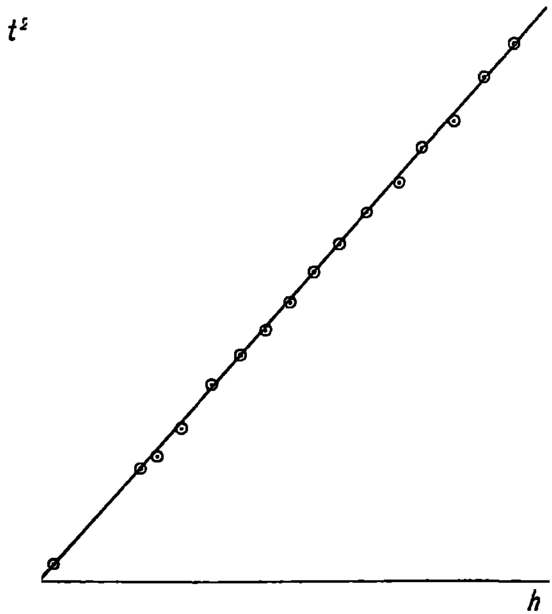


FIG. 3.

the platform before the pendulum passes the mid-position on its return swing, the bell rings. When the platform is adjusted for the greatest fall for which the bell will ring,

the time of fall must be equal to the half-vibration period of the pendulum. The pendulum can be timed by a watch ; the height of fall is measured on the scale on the standard. From these results g is calculated.

The apparatus is in two parts. One is a standard with a 5-ft. scale by which the position of the movable platform can be regulated.

The other portion carries the pendulum and the bell which sounds when the platform is in the correct position.

The necessary connections are shown in Fig. 2, and are so arranged that it is impossible to connect up wrongly.

An error of 0·01 sec. is possible and one of 0·003 sec. is usual; though the machine is not designed to attain greater accuracy than this, results are often obtained which are not in error by 0·001 sec.

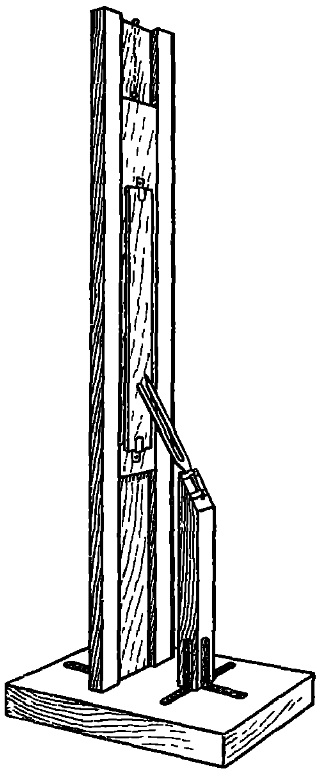


Fig. 4.

2. THE FALLING PLATE

Alexander Hill

The apparatus shown, with the exception of the fork, which is an ordinary middle C (256), was made in the manual instruction room at very little cost. The sliding part is made very loose, so that it can fall without touching the frame. A small wedge of photographic film is attached to the end of the fork by a blob of sealing-wax, and the fork is fixed in the stand by two metal clips. The smoked glass

is attached by clips to the sliding part, and the latter is tied to the top by a short piece of thread. Some folds of blotting-paper may be placed in the bottom to break the fall. The fork is bowed with a violin bow and the thread burnt simultaneously. The plate is then removed and examined. If it has fallen freely, the track of the wave should be perfectly straight. This can be checked by holding the plate up and looking along the surface.

It should now be quite easy to show that each wave has been executed in the same time ($\frac{1}{256}$ sec.), and that the speed is obviously increasing all the way down. Hence there is acceleration.

If the experiment is done collectively as a demonstration, a number of glass plates can be passed round for measurement. Quite satisfactory results can be obtained by measuring with a steel ruler, although older pupils might be taught to use a travelling microscope.

With a 256 fork, the waves should be grouped in eights by placing a small pin-scratch near the crest of every eighth wave.

This simplifies the arithmetic, since eight vibrations will represent $\frac{1}{32}$ sec.

No further equation or formula is necessary. The measured lengths are filled in on the table shown, and the value of " g " comes out automatically.

Length of sector.		Average speed.	Increase of speed each sector.		Acceleration.
(Dist. per $\frac{1}{32}$ sec.)		(Dist. per sec.)	(I.e. increase per $\frac{1}{32}$ sec.)		(Increase per sec.)
1·51 cm.	× 32	48·30 cm./secs.	> 30·72 cm./secs.	× 32	983 cm./secs.
2·47 ,,	,,	79·02 ,,	> 30·43 ,,	,,	974 ,,
3·42 ,,	,,	109·47 ,,	> 30·90 ,,	,,	989 ,,
4·39 ,,	,,	140·37 ,,	> 30·68 ,,	,,	982 ,,
5·35 ,,	,,	171·05 ,,			

It is important to notice the advantages that this experiment has over the usual " pendulum and bob " experiment, quoted in so many textbooks :

(i) The idea of acceleration is clearly shown on the smoked plate.

(ii) It measures acceleration direct and demands no previous knowledge of equations of motion, nor, in fact, of any part of mechanics, except the definition of acceleration.

(iii) An accuracy of 1 per cent. error can be obtained with the simplest of apparatus.

3. A "FREE-FALL" APPARATUS

S.S.R., (X) 39

The apparatus consists of a board, about 30 × 4 in., arranged to slide vertically between guides fixed to a back board. It is supported electromagnetically by using an accumulator, which also provides current, "in series," to another electromagnet fixed on the side at the lower end. The latter attracts a light spring which carries an inked brush. A piece of paper is pinned on the board and the current switched off; a trace is obtained from which the fundamental principles of acceleration can be studied.

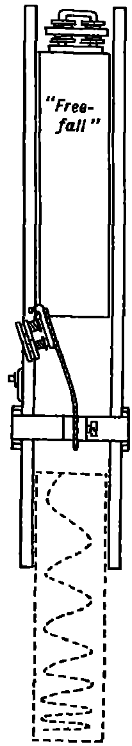


Fig. 5.

4. ATWOOD'S MACHINE

W. G. Allanson

The figure shows a simple form of the "ribbon-Atwood." The vibrating brush is carried at the end of a metre rule clamped at its lower end. The trace is made on a strip of paper, pinned to an ordinary school ruler or wooden lath with bevelled edges, running between the two lower pulleys. Using the apparatus, a class of boys can prove: (*a*) acceleration varies as moving force for a constant mass; (*b*) acceleration varies inversely as the mass moved for a constant moving force.

By comparing the vibrations of the metre rule with those of a loaded and more slowly vibrating one, the actual time of a vibration can be found, and hence the value of g.

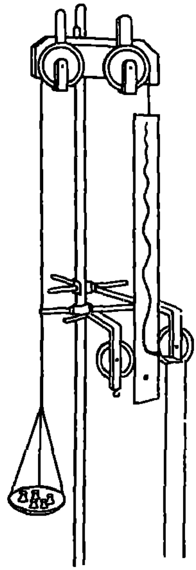


FIG. 6.

5. A SIMPLE TROLLEY

H. F. Biggs

The trolley is supported on three steel balls, on which it rolls. These balls form a low isosceles triangle, ABC, the two, A, B, at the base, running along a guide, g, near one side of the bed, and the third, C, running on a parallel guide at the other side. On the bottom of the trolley is a corresponding long guide running on the balls A and B, while on C runs a piece of plate-glass, P. The ball, C, itself can be made to run on a guide like that for A and B, but it would be theoretically more perfect to have it running with plate-glass below as well as above, thus avoiding the slight sliding friction caused by lack of parallelism between two guides on either trolley or bed; then something of the nature of a

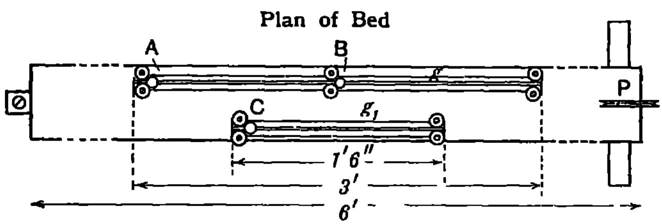


FIG. 7.

little socket would have to be placed on the glass at the starting-point to keep the ball in position.

Each guide is simply formed of a pair of glass tubes

(" rails ") kept apart by a small glass tube between them. About 7 mm. (the thicker the better) for the " rails " and 3 mm. for the spacing tube are dimensions that answer

Plan of Trolley (bottom up)

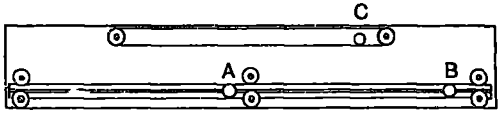


FIG. 8.

very well with $\frac{7}{16}$-in. steel balls (sold for 1*d.* each at any motor garage). The guides are held by washers fastened by screws, round-headed for preference. These should be in pairs on opposite sides of the guides, and spaced not more than 6 in. apart, so that when the trolley is loaded, the guides will not be forced apart by the balls between the points where the tubes are fastened. The tubes take up the general contour of the wood on which they lie, and, therefore, if great perfection is desired, although it is no use choosing specially straight tubes, the bed and trolley should be planed with some care, or the tubes packed up with paper where the wood dips, to get them truly level all along. However, such refinements are unnecessary if one is content with a trolley that will run with an obvious acceleration down a slope of one in a thousand, or when pulled along on the level by a weight of 2 grams. Small wriggles of the guides from side to side are immaterial, especially if the apex ball, C, runs on a plate.

Section of Trolley and Bed

FIG. 9.

The vibrator, a mild-steel strip, is fixed between the stems of three stout 3-in. screws in the *side* of the beam

(4 in. wide by 3 in. deep) which forms the bed. The brush then makes its trace on a vertical side fitted to the trolley. It is an advantage to have this one-sided weight, since it brings the centre of gravity nearer the base of the triangle of support, and so allows the trolley a longer run without toppling over ; the same end can also be gained by having the rails, AB, well in from the side of the apparatus. Of course, the trolley is then even more liable to be knocked over, but it is easy to arrange guides clearing the trolley by a few millimetres which will prevent such disasters. With a run of 50 cm., about twenty waves are traced on the paper when a weight of 5 grams pulls the trolley along the level ; and when first differences are taken over ten waves, and second differences over five waves, the results agree within 10 per cent. ; but greater accuracy could be gained by careful planing.

6. KATER'S PENDULUM

F. A. Meier

Kater's pendulum, as supplied by dealers, is an unnecessarily large and expensive piece of apparatus. Results accurate to $\frac{1}{20}$ per cent. for g can be obtained with a pendulum much reduced in size and weight, which can be constructed for 2*s*. Only the simple operations of drilling, tapping, filing and sawing are required, though of course a better finish can be obtained with a lathe. Care must be taken not to make the pendulum too light, for experiment shows that a light pendulum is affected to the extent of about 1 sec. in 600 secs. by the air resistance.

The design given below has been very thoroughly tested both in air and in a vacuum, and is guaranteed to give results to within $\frac{1}{20}$ per cent., for g, if a good watch is used. The masses have been chosen so that air resistance is negligible, as can be seen by inspection of the table below for this pendulum swung in air and then in a vacuum.

No. of swings.	Time in air (secs.).	Time in vacuo (secs.).
100 . . .	119·0	118·8
200 . . .	237·8	237·8
300 . . .	356·6	356·6
400 . . .	475·4	475·6
500 . . .	594·4	594·6
600 . . .	713·6	713·6
700 . . .	832·4	832·6
800 . . .	951·4	951·4
900 . . .	1,070·2	1,070·4

With a stop-watch, tested and found to be accurate to $\frac{1}{5}$ sec. in 1 hour, no measurable difference of time is observed for 18 mins.; the difference between the end times is attributable to the stop-watch error. This means that the air affects the result not more than 1 part in 5,000.

Construction of the Pendulum.—This is most easily understood from the diagram. The knife edges K_1 and K_2 are safety-razor blades fastened to a small sliding piece, C, in Fig. 10, by two small set-screws, *a* and *b*, passing through the two outer holes of the blade. A small screw, P, shown in the smaller figure, clamps the metal piece to the pendulum rod. The knife edges are set on the same side of the rod, and to restore the balance and make the rod hang vertically, the circular weight W is drilled eccentrically. The holes in the blade are large, and permit of accurate adjustment of the blades at right angles to the rod. For safety, the edges of the blades are blunted by rubbing them on fine emery cloth. The support for the pendulum is a flat piece of metal with a slot in which the pendulum may swing, and a small hole about an inch distance from the edge of the slot for the simple pendulum to hang beside the Kater's pendulum. N is a nut for fixing the thread of the simple pendulum. The hole for the thread is large at the top ($\frac{1}{8}$ in.), and ends in a small hole which may be made by hammering a stout needle through the remaining small thickness of metal. The length of the simple pendulum may then, without sensible error, be measured from the lower surface of the plate.

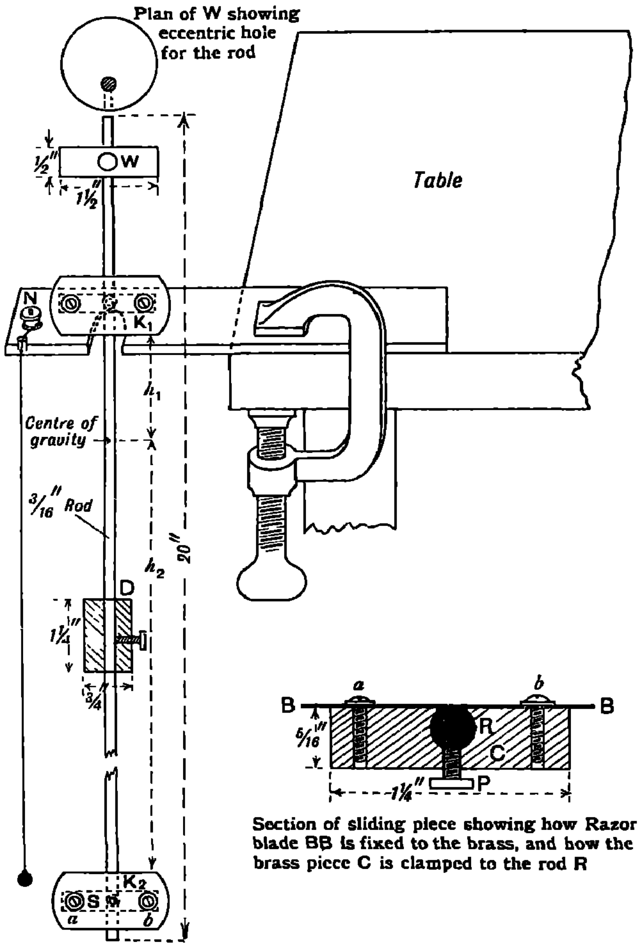


FIG. 10.

Approximate weight of pendulum	$= \frac{3}{4}$–1 lb.
Sliding weight W	$= 5$ oz.
Sliding weight D	$= 3$ oz.
Total cost (not including the blades)	$= 2s.$

Method of adjusting the Pendulum so that the Times of Swing about the Two Knife Edges shall be equal or nearly equal.

Fix the knife edges approximately as shown in the diagram and keep them fixed throughout the experiment. Adjust a simple pendulum with a very small bob (a bicycle ball-bearing, $\frac{1}{4}$ in. diameter, is suitable if a small loop of flexible copper wire be soldered to it). The length of this pendulum, as measured from the centre of the bob, must be made equal to the distance between the knife edges. Adjustment to within 1 mm. is not difficult.

The two pendulums are hung side by side on the support described previously and shown in Fig. 10. If they are not isochronous, the weight W, which should be at *the bottom* to start with, is shifted slightly until the simple pendulum does not gain or lose half a swing in 50 complete swings. No further adjustment need be made, and it only remains to take the time of swing accurately about the two edges.

The value of g is worked out from the formula—

$$\frac{8\pi^2}{g} = \left(\frac{T_1^2 + T_2^2}{h_1 + h_2} + \frac{T_1^2 - T_2^2}{h_1 - h_2}\right);$$

the second term in the brackets being small, only approximate values for h_1 and h_2 (the distances from the knife edges to the C·G· of the pendulum) are required.

BOYLE'S LAW

7. BOYLE'S LAW APPARATUS

Rev. B. G. Swindells, S.J.

To make the apparatus shown in Fig. 12, two glass tubes (about $\frac{3}{8}$-in. diameter) are cut about 6 in. to 8 in. long, and the ends made suitable for taking the pressure tubing. One of the tubes is, of course, closed, and the closed end should be flattened; the other tube is best made funnel-shaped at the end to facilitate the pouring in of the mercury. A further refinement, which is not necessary but a great improvement, is to seal a side reservoir on to

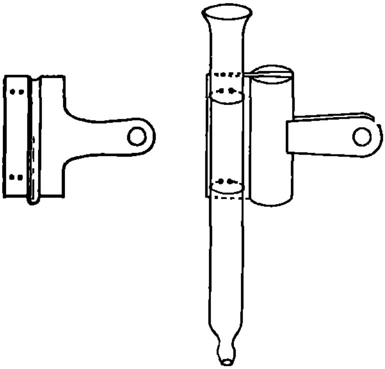


FIG. 11.

the open tube; this eliminates the danger of an overflow of mercury.

The open tube is then wired on to one of the jaws of a "bull-dog" clip. To do this the jaw is taken out of the spring, two pairs of small holes are drilled in it and a wire is passed through each pair. The wire is then twisted round the tube. The pressure tubing is then wired on to the two glass tubes.

If the only metre scales available are those graduated along one edge, the closed tube should be wired on to this edge of the scale, as in the figure. If this wiring is made fairly loose, the tube can be slipped on or off the metre scale as required. The open tube is clipped in any desired position on the other edge of the scale. If, however, metre scales are available which have the graduations down the centre, both tubes may be attached to "bull-dog" clips, and clipped one to each edge of the scale. This is, of course, a more convenient arrangement. The metre scale is held upright by two clamps on a retort stand.

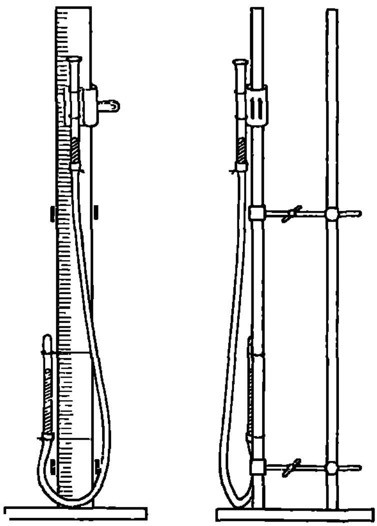


FIG. 12.

The cost of this Boyle's

Law apparatus, if the special components alone are considered, is covered by a few pence. Yet, if a set-square is used to avoid parallax in the readings, an average boy will find "PV" to be constant to 1 in 400 or 500, while an accuracy of 1 in 700 or 800, or even more, is often obtained.

8. TO VERIFY BOYLE'S LAW WITH A BICYCLE PUMP

F. A. Meier

The details of the apparatus can be most easily understood by referring to the perspective sketch (Fig. 13). The pump is an ordinary Bluemel bicycle pump of internal diameter ¾ in. When buying such a pump, it is best to check the diameter with calipers, as it seems customary to specify pumps by their external diameters. The wooden handle is removed by filing the metal at the end, until the handle can be slipped off. In its stead, a small piece of metal rod is soldered into the tube, as well as a small metal cross-piece, M, to which the cords can be attached. A shallow recess, R, is made in the block of wood into which the lower end of the pump barrel can fit, to prevent it from slipping; the block, K, is clamped to the table. A

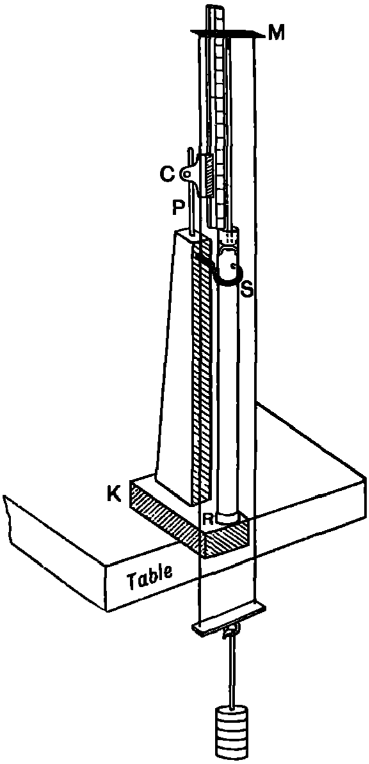


FIG. 13.

" bull-dog " clip, C, soldered to a piece of knitting pin, P, is a convenient arrangement for holding the scale for measuring the volume. This scale should rest on the top end of the pump barrel. It measures the volume of air in the barrel in cms. of tube, and not in c.c. The method adopted for closing the lower end of the pump is the same as that described and shown in Fig. 27, p. 25.

Pressures up to 8 atmospheres can be used without damaging the pump, and if the washer is soft and well oiled, the small amount of leakage, if any, is remarkable and most unexpected. When carrying out the experiment, the weights are placed on the hanger, and the plunger should reach its new position of equilibrium *without any touching on the part of the experimenter. Only in this way can leakage be avoided.*

Below is given a table of results taken with the apparatus. The total force on the piston, of course, includes the weight of the piston and accessories, together with the atmospheric pressure.

Total force on piston in lb. P.	Volume. V_1	$\frac{1}{\text{Volume.}}$	P.V.
8·5	8·66	·118	73·6
10·5	7·08	·141	74·4
12·5	5·94	·168	74·5
14·5	5·10	·196	74·0
16·5	4·48	·224	73·8
18·5	3·99	·251	73·8
20·5	3·61	·276	74·0
22·5	3·28	·305	73·8
24·5	3·01	·332	73·8
26·5	2·80	·356	74·1
28·5	2·59	·386	73·8
30·5	2·43	·412	74·0
32·5	2·28	·438	74·0
34·5	2·14	·468	73·7
36·5	2·01	·497	73·6
38·5	1·91	·523	73·6
40·5	1·81	·552	73·4
42·5	1·73	·578	73·4
44·5	1·66	·601	73·6
46·5	1·58	·632	73·4
48·5	1·52	·658	73·6
50·5	1·46	·683	73·7

Mean P.P. = 73·8

No doubt many teachers have found that the ordinary Boyle's Law apparatus gives only a very small part of the hyperbola which can hardly be distinguished from a straight line. The unfortunate result is that only too many boys, when they have obtained what they believe to be a straight line, draw the conclusion that Boyle's Law is true. This deplorable result cannot occur if pressures up to 8 atmospheres are used.

Greatest deviation from the mean is less than 1 per cent.

P.S.—The idea of using a bicycle pump to verify Boyle's Law was, I believe, originally due to Mr. Anderson, of George Watson College, Edinburgh, but I do not know whether he designed a suitable form of apparatus.

DENSITY

9. RUBBER BALLS FOR DENSITY WORK

S.S.R., (III) 9

Solid rubber balls, 1 in. in diameter, are useful for density work. They sink slowly in water, but float if a little salt is dissolved in the water. The relative density of rubber is 1·03.

10. ARCHIMEDES' PRINCIPLE

Rev. W. Burton

The base of a 6 × 1 in. test-tube is flattened by heating it in the blowpipe flame and gently pressing it, while hot, on a flat surface. A narrow strip of squared paper, ruled in cms. and mms., is then pasted down the inside. When weighted with leadshot and hung from a spring balance, it is immersed to various depths in liquids and the upward thrust observed for various depths of immersion. The cross-section of such a tube is nearly 5 sq. cm., and with a spring balance reading to 100 grams, a convenient series of readings can be obtained. It can, of course, be used as a simple hydrometer.

11. ARCHIMEDES' PRINCIPLE

K. H. Cochran

Graduate a glass jar to measure ounces of water (a Nicolson hydrometer jar does very well). This is done to a sufficient degree of accuracy by pouring in 453·6 c.c., marking the surface A (1 lb.), then adding a second pound, and so obtaining B. Rub the surface of the jar from A to B with a carborundum hone, which will give a matt surface on which graduations may be marked in pencil. Divide AB into 16 equal parts.

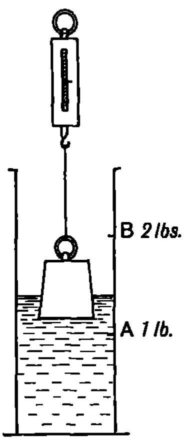


FIG. 14.

Use a spring balance reading 4 lb. × 1 oz. or ½ oz. ("Sportsman's" Tubular Balance). Suspend a kilogram weight and read the balance to nearest ounce. Read the water level, which should be adjusted exactly to a mark on the scale. Now partly immerse the weight and read balance and ounce scale again. The difference between the readings of the balance gives the upward thrust, and the difference between the scale readings is the weight of water displaced.

By this method the truth of the principle for partial and for total immersion may be shown. The graduated ounce scale also enables the *weight* of displaced fluid to be read directly.

The same jar may be used to demonstrate the truth of the principle for other liquids if two or more ounce scales are added, e.g. one for alcohol and the other for turpentine. The first jar may also be used to find relative densities of floating bodies. The body, when floating, displaces its own weight of water. Total immersion gives the weight of an equal volume of water.

Results are read to the nearest ounce only. The lower portion of the jar is not graduated for obvious reasons.

12. SIMPLE ILLUSTRATIONS OF ARCHIMEDES' PRINCIPLE

J. D. Peterkin

No. 1.—Fit up the apparatus shown in Fig. 15. A is a toy balloon, B its wooden mouthpiece. Attached to B are CD, a long rubber tube, and E, a 20-gram weight. F is a tall, wide, glass jar filled with water. Blow into the tube at D. The balloon expands and displaces more water. The upthrust increases, and the balloon rises.

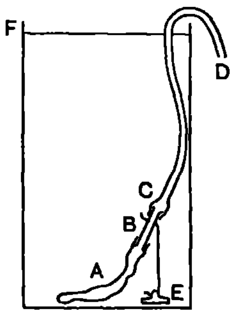


Fig. 15.

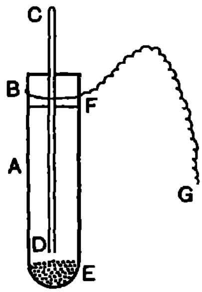


Fig. 16.

Allow air to escape at D, and the balloon sinks.

Set up a similar apparatus, employing a balloon of the same size, but using a heavier weight, say, 50 grams, at E. Blow up the two balloons side by side.

No. 2.—Fit up the apparatus shown in Fig. 16. A is a boiling tube ; B a one-hole stopper ; CD a rather wide glass tube closed at C : and G a long thread tied on to the boiling tube at F.

Add shot, E, to make the apparatus *just sink* in water.

Lift the apparatus out of the water by means of the thread. Pull up the tube, CD, so as to lengthen the por-

tion above the stopper. The apparatus now displaces more water, and is able to float: it is easy to make it sink.

13. THE FLOTATION BOX

G. N. Pingriff

This has proved very useful for the study of the Law of Flotation. The boxes are made in the school workshop of $\frac{1}{4}$-in. wood, of such a width that they will stand on the balance scale pans. Paper scales are gummed to two diagonally opposite corners, and pieces of sheet lead placed on the bottom of the box. Molten paraffin wax is then poured on to the lead, and when this has set, the whole box is oiled and varnished within and without. In experimenting with the box, a set of readings is taken in which displacements of water (very easily calculated from the depth) are compared with total floating weight. Any displacements up to about 200 grams can be obtained with the box shown (the figures in the two columns seldom differ by more than one or two units). In taking the depth, readings are taken on both scales in case the box has a list.

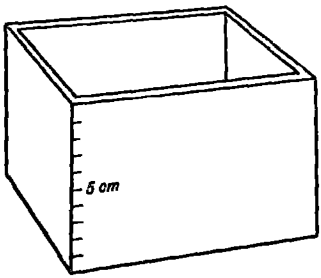


FIG. 17.

14. HYDROMETERS FROM BROKEN PIPETTES

S.S.R., (XII) 45

Pipettes which are spoilt by chipping at the tapering end may be converted into hydrometers by blowing a bulb, as shown. The construction forms an interesting study in stability. The sizes given are approximately correct for a 25-c.c. pipette. In some cases it is necessary

to replace the upper tube by thinner-walled tubing or to shorten this tube.

The calibration of such a hydrometer, by using salt solutions of various strengths, the densities of which are obtained first by S.G. bottles, has been found successful in a first-year science class. Regular graduations may be obtained by interpolation on a depth-density graph. A paper scale can be fastened inside by sealing-wax. (These materials must be inside during calibration measurements.)

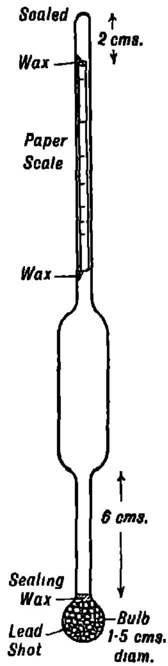


FIG. 18.

15. CARTESIAN DIVER

G. D. C. Mason

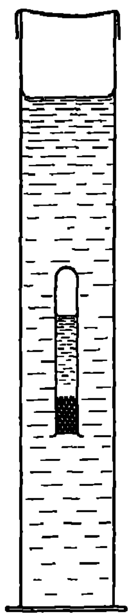


FIG. 19.

The jar is fairly tall (those used in resonance experiments are quite satisfactory), so that a reasonable depth of water is obtained. An air space of an inch or so is left at the top, which is covered with a piece of sheet rubber from an old football bladder, held in place by a rubber ring. The test-tube has a piece of folded copper gauze at its mouth, of such a size that when the tube is partly filled with water and inverted in the jar, it will just float inverted in the water.

If now the rubber sheet is placed in position, the test-tube will behave like a Cartesian diver, but with the advantage that the change of water level inside the tube is easily visible as it sinks and rises.

16. LEVER METHOD FOR SPECIFIC GRAVITY

S.S.R., (V) 18

The specific gravities of an insoluble solid that sinks in water, an insoluble solid that floats in water, and a liquid, are easily found by using a simple lever. The method has several advantages. There is no risk of damping and spoiling a good laboratory balance, and no " weights " are needed.

Case 1.—*Solid, W, heavier than water.*

Take a metre rod, bored and supported by a horizontal needle at O, the 50-cm. mark. On the left side, at A, hangs the body W whose specific gravity is to be found. Balance the lever by hanging on the right side, at B,

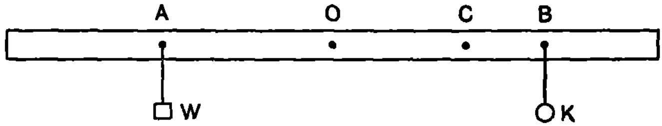


FIG. 20.

any suitable mass, K. Place a beaker of water under W so that W is immersed, and move K until the lever again balances. K is now at, say, C. Then—

$$\text{Specific gravity of W} = \frac{\text{OB}}{\text{BC}}.$$

Checks are easily made by varying the position of A.

Case 2.—*Liquid L.*

Three readings are taken. The first and second, B and C, are found exactly as in Case 1. W is next immersed in the liquid L, and a fresh balance point, D, is found.

$$\text{Specific gravity of liquid L} = \frac{\text{BD}}{\text{BC}}.$$

Case 3.—*Solid lighter than water.*

Take two sinkers of the same material, but not necessarily of the same weight. Balance them, one at A on

the left, the other at S on the right. Hang W at A, and balance it by K at B. Conditions are now as shown. Now immerse W and its sinker in water, and also immerse the sinker at S in water. The upthrusts on the two sinkers have equal moments about O, and all we have to do is to move K until a balance is again obtained. K goes to,

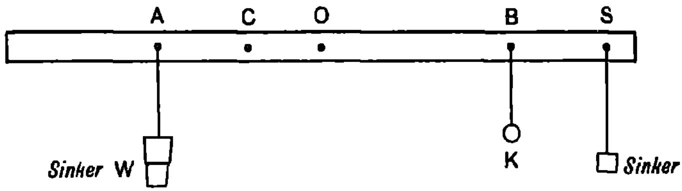


FIG. 21.

say, C, which will be on the left of O. Then—

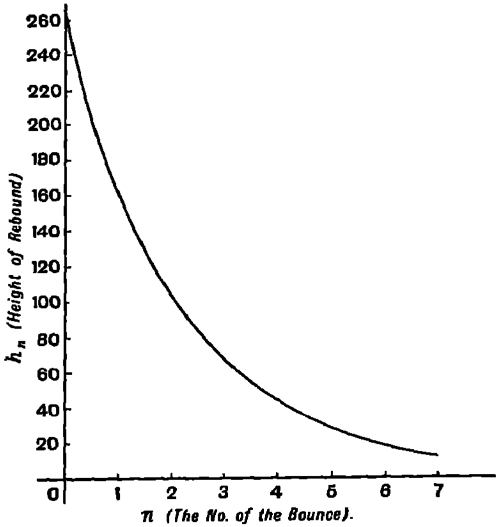
$$\text{Specific gravity of W} = \frac{OB}{BC}, \text{ as in Case 1.}$$

17. SPECIFIC GRAVITY OF A SOLID LIGHTER THAN WATER

S.S.R., (V) 18

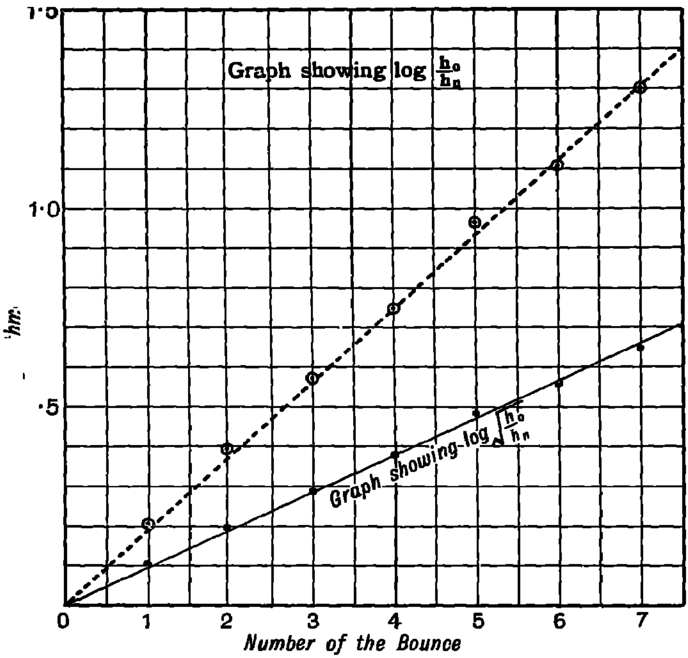
The usual laboratory sinker method of finding the specific gravity of a solid lighter than water may be simplified considerably. Hang a 20-gram brass weight from each arm of the balance. To one fasten the solid in question over the left-hand pan, and add weights to the right-hand pan to bring the beam to the horizontal. Call these weights W_1. Do not remove them from the pan. Immerse both sinkers (one with the body attached) in water. Add weights, W_2, to the left-hand pan to balance again. These weights clearly measure the upthrust on the body. Then—

$$\text{Specific gravity} = \frac{W_1}{W_2}.$$



260
240
220
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
h_n (Height of Rebound)
n (The No. of the Bounce).

FIG. 22.



1·5
1·0
·5
0
1
2
3
4
5
6
7
Graph showing log $\frac{h_0}{h_n}$
Graph showing log $\sqrt{\frac{h_0}{h_n}}$
Number of the Bounce

FIG. 23.

ELASTICITY

18. COEFFICIENT OF RESTITUTION

E. J. Atkinson

A golf-ball is allowed to fall freely vertically upon a steel plate which can be adjusted for horizontal, and the heights of successive rebounds noted.

A convenient starting height is 256 cm. Thin rods, placed out horizontally from an upright, serve to mark the heights of the bounces, because it can be seen clearly when a rod is too high or too low. The positions of the several rods will show how the heights diminish, a fact possibly better illustrated by plotting h_n against n as shown in graph (Fig. 22). The straight line obtained by plotting $\log \sqrt{\frac{h_0}{h_n}}$ against n, as shown in graph (Fig. 23), shows the constancy of $1/e$ and thus of e.

FORCE

19. PHYSICAL INDEPENDENCE OF FORCES

S.S.R., (VII) 25

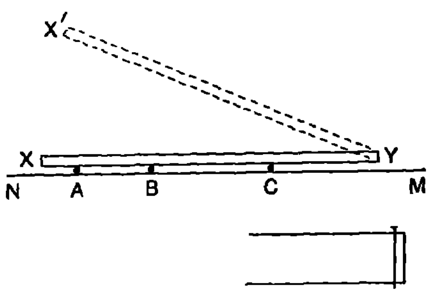


FIG. 24.

NM represents the edge of a table, a half-metre rule, XY, being held on its edge ½ in. from and parallel to it. A, B and C are pieces of chalk or other small objects touching the ruler. The latter is rotated horizontally by the hand at Y to the position YX^1 and then brought smartly back to its original position.

The objects A, B and C are projected with different horizontal velocities, but all reach the floor at the same time. This latter fact is easily ascertained by listening rather than seeing.

Should any difficulty be experienced in moving the ruler with the pivot end, Y, at the same spot, as is necessary for the success of the experiment, a small wire nail should be fixed so that its tip projects through the ruler in the manner shown in the smaller diagram.

PRESSURE

20. MEANING OF THE WORD "PRESSURE"

J. D. Peterkin

Cut a wooden cube into the shape shown in the figure, the face AB being 1 sq. in., the face CD much larger.

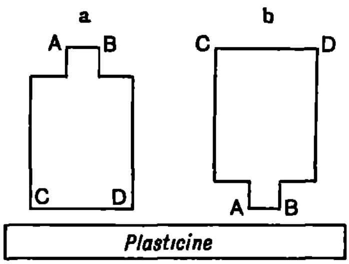


FIG. 25.

Prepare a flat cake of plasticine, at least an inch in thickness. Upon it place the block in the position shown at (*a*); then stand a boy upon the face AB.

Move the block to another part of the plasticine, placing it in the position (*b*). Set up the experiment near a wall so that the boy may place his fingers on the wall in order to keep his balance. Compare the imprints made by the block in the two positions.

21. WATER PRESSURE

J. D. Peterkin

Fit up the apparatus as shown. AB is a large vessel with outlet (a Hope's apparatus will do). C, D, E, are glass tubes, C for an inflow of water from the tap, D for

an outflow, and E to show the water level in the apparatus itself. Turn the tap a little, so that the water rises in E.

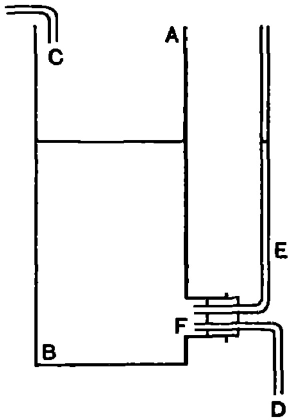


FIG. 26.

The pressure at F increases, till the outflow at D is equal to the inflow at C. The level in E then remains constant.

Turn off the tap a little. The falling pressure at F reduces the outflow till it is equal to the inflow; the water level is again constant, but lower than before.

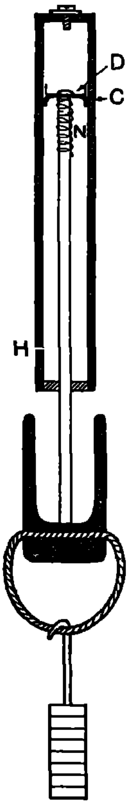


FIG. 27.

22. TO MEASURE THE PRESSURE OF THE ATMOSPHERE WITH A BICYCLE PUMP

F. A. Meier

An ordinary bicycle pump (Fig. 27), $\frac{3}{4}$ in. internal diameter, is suitable. The open end is stopped up with a small set-screw and leather washer so as to be quite air-tight. The cup leather, C, and small metal plate, D, must be reversed and screwed on again as shown in the figure. There is no difficulty in this. A hole should then be drilled in the handle and a loop of stout cord attached by which weights may be lifted. They should be so adjusted that they can just be lifted without pulling out the piston, or so that the piston is just pulled down. It will be found that a dead weight is more satisfactory than a spring balance.

To make it more convincing that it is the atmospheric pressure that is supporting the weights, a small hole, H, may be drilled 2 in. from the lower end of the barrel. As soon as the cup leather passes this point, the air will be heard rushing in, and no weights at all can be supported. It is advisable to leave in the spring, N, as it prevents damage to the cup leather. To secure success, the main thing is a really soft and well-oiled cup leather. The oil should be thick machine oil.

When starting the experiment, the piston must be pushed in as far as it will go, to expel the air in the barrel. Even when pressed fully home, a small volume of air is left in the pump, but this is too small to affect the result materially. Taking the atmospheric pressure on a given day to be 14·7 lb./sq. in., results of the order 14·9 or 14·4 can be obtained.

ROTATION OF THE EARTH

23. FOUCAULT'S PENDULUM

R. H. Smith

This experiment can be carried out easily in schools where there is a deep staircase well.

The pendulum is supported on a wooden beam, cross-section $7 \times 1\frac{1}{2}$ in., which is clamped tightly in a horizontal position across the well. In the centre of the beam a bed of felt is fixed, and on this a rectangular glass prism, $3 \times 1\frac{1}{2} \times \frac{1}{5}$ in. Projecting rims should be raised to hold the felt and the prism in place.

The pendulum is made of a rectangular wooden framework (Fig. 28) of eight pieces of $\frac{1}{2}$-in. wood, nailed securely together, from which the wire hangs; the frame is large enough to leave ample space when swinging around the beam. A steel ball-bearing, diameter $\frac{7}{8}$ in., is embedded centrally under the top part of the frame, and the bearing rests on the glass prism. A narrow hole is drilled centrally through the lower part of the frame, and through it the

pendulum wire is passed and wound symmetrically. It is held in position by small staples driven into the wood. The wire should be steel pianoforte wire, diameter about 1 mm., and as long as possible. The bob is made thus: a stout copper wire is fastened through the bottom of a

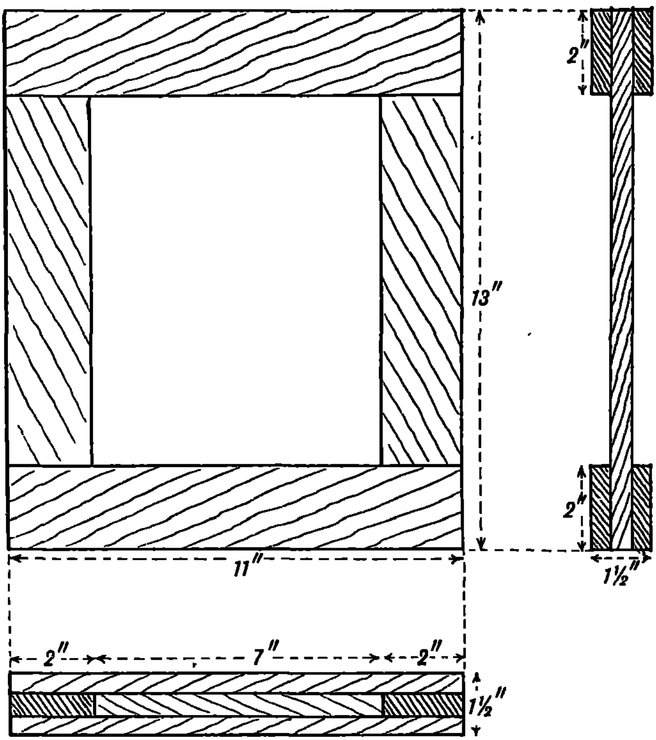


FIG. 28.

cylindrical tin, height 6 in., diameter 5½ in.; a ring in the top of the wire enables it to be fastened to the steel wire. The tin is filled with cement, which is allowed to set.

The pendulum is allowed to hang for twenty-four hours to remove torsion in the wire. The experiment should be done at a time when the doors upon the staircase are closed and draughts eliminated.

In an experiment with a pendulum 22 yds. long, the period was approximately 9·5 secs., the amplitude after 90 minutes was 4–5 in. The rotation measured was 13°. The calculated amount of rotation per hour is 11·5°.

SURFACE TENSION

24. EXPERIMENTS ON SURFACE TENSION

J. Howard Brown

1. Suspend a glass plate horizontally by cotton and wax from a balance arm, and counterpoise. Raise the water in a shallow tray so that the surface touches the plate pushed down to make contact. Add weights to pull away the plate. (For ordinary gas-jar plates, this will be about 30–32 grams.) Repeat with other liquids, e.g. alcohol.

2. Put a needle on blotting-paper or tissue-paper and float this on water. The paper sinks and leaves the needle floating on the surface. (Rub the needle between the fingers first.)

3. Make a jumping frame from a broken pipette carrying a horizontal wire frame above the bulb, weighted with mercury so as to float with the frame 1 cm. or so above water. Hold the frame below the water and let go; it will not break through the surface.

4. A paraffined sieve. Lay a piece of wire gauze on a circular block so that 1 in. overlaps; turn down the edge and wind wire around to keep it tight. Dip into melted wax and shake the wax out of the holes. The sieve will float on water, and water can be poured into it (on paper to break the fall) without running out.

5. Float two matches on water, placing them parallel and 1 in. apart; touch the water between them with wire moistened with alcohol. The matches spring apart.

6. Cover the bottom of a white photographic dish with coloured water and touch the surface with a glass

rod dipped in alcohol. The liquid leaves that part, making the bottom of the dish dry. Repeat with ether.

7. Repeat experiment 5, touching the water between the matches with a hot wire. They spring apart, showing the lower surface tension of hot water.

8. Sprinkle sulphur powder on water in a shallow metal dish (such as a large tin lid) and heat the edge with a Bunsen burner. The part of the water above the flame is rapidly swept clean of sulphur.

9. Repeat experiment 2, adding soap solution to the water on which the needle is floating; the needle then sinks.

10. Twist a thin wire into a flat spiral and float it on water. Drop a little soap solution into the centre of the spiral; it then begins to rotate.

11. Rub soap on one end of half a tooth-pick and float on water. It moves about over the water.

12. Fasten a small piece of camphor to the stern of a tiny wooden boat and float on water. The surface tension of the water in front dragging the boat forward is greater than that of the camphor solution behind, so that the boat moves forward. The boat may be cut from thin aluminium foil, to which a thin circle of cork is gummed, holding a "mast" of drawn-out glass tubing. A paper "sail" completes the boat. The experiment is best done in a large photographic developing dish.

13. Weight a tube 3–4 cm. long and 5 mm. diameter, and having a cork about the middle, to float with the open end just flush with the water. Put one drop of oil on the water as far away as possible: the model sinks when the oil reaches it. (Given in Latter: *Studies of Living Things*, to illustrate method of clearing ponds, etc., of gnat larvæ.)

14. Form a soap film on a wire triangle (about 2-in. side); place a match stalk or needle across, parallel to the base, and break film on this side. The match is pulled towards the apex.

15. Tie a loop of fine thread across a wire ring 2 in.

in diameter and dip into soap solution to form a film. Thrust a hot wire through the film inside the loop ; the thread instantly becomes a circle.

16. Form a soap film across the mouth of a clean 2-in. funnel and hold the stem upright. The tendency of the film to contract lifts it against gravity.

17. Blow a bubble of 2–3 in. diameter on the bowl of a pipe ; on standing, it shrinks and disappears into the pipe, and also deflects a candle flame held opposite to the mouthpiece.

18. Mix 9 volumes of spirits of wine (not methylated spirit, which becomes cloudy) with 7 volumes of water in a glass jar with flat sides. Introduce a very little water half-way down by means of a pipette ; this makes the liquid below a little heavier. Drop olive-oil from a tube into the liquid. If it sinks, add more water to the lower half ; if it floats, add more spirit to the upper half. The drop is perfectly round.

19. Half-fill a jar with coloured water and fill up with paraffin to which a little carbon disulphide has been added to make it only slightly lighter than water (11 volumes to 16–17 of paraffin). Dip a wide tube into the water and raise, so that drops fall slowly through the paraffin. Carbon disulphide or zinc sulphate solution may be used in the same way.

20. The lower end—5–10 mm. diameter—of a dropping funnel containing aniline dips into water at about 60°. (The density of aniline at 64° is equal to that of water.) Open the tap slightly ; drops of aniline fall slowly through the water, so that their formation can be watched.

21. Clean two glass plates, 3–5 in. square, with soap and hot water. Separate them at one edge by a match stalk and hold in position by a rubber band. When this is dipped into water, the water rises ; as the distance between the plates diminishes, it rises farther, so forming a hyperbola.

22. Draw out capillary tubes with diameters of about 1, ·7, ·3 mm., clean carefully with sulphuric acid, followed

by distilled water. Fix vertically in a beaker of liquid. When the rise has finished, raise the tube about 1 cm. so that the liquid may flow back on the wetted surface. Read the height by means of dividers and add $\frac{1}{3}r$ to correct for meniscus error; find bore of tube by mercury weighing method; verify Law of Diameters (rise $\times$ diameter $=$ constant) and calculate the surface tension of the liquid.

23. Make a rectangular frame of platinum wire, $3 \times 1\frac{1}{2}$ cm. Clean in a flame and hang vertically from a balance so that it dips in water with 3 mm. above the surface. Add weights to balance. Now immerse the frame in water; it will have taken up a film of water on rising, and more weights will be required to balance. Difference $=$ pull of film $= \cdot 4$ gram (approx.); and surface tension $=$ pull $\div$ 2 length.

24. Hang a small circular copper wire ring (freed from grease with soapy water) from a balance so that it rests on the surface of water in a dish on a bridge. Add weights to pull the ring away from the surface, when surface tension $=$ pull $\div 2 \pi d$.

Note.—For these experiments, the water must be perfectly clean: even contact with the fingers seriously reduces the surface tension.

25. FURTHER EXPERIMENTS ON SURFACE TENSION

Cambridge, 1923

1. Waves of the same period are produced in two $\frac{1}{4}$-plate porcelain developing dishes containing water and soap solution respectively by means of a vibrator agitating a rectangular wire frame in each. The surfaces are illumined intermittently by light passing through a rotating pierced plate and reflected by 45° mirrors on to the surfaces of the liquids, and by synchronisation the effect of stationary waves is produced stroboscopically. These waves are of very different, and measurable, lengths.

2. Drops of water are delivered slowly from burettes

into acid and alkaline media of nearly unit density, with which the water does not mix, or only slightly. The different sizes of the spherical drops show the variation in surface tension.

26. ANGLE OF CONTACT AND SURFACE TENSION

Oxford, 1921

Fig. 29 illustrates a very simple method of measuring the angle of contact of a liquid. A microscope slide, covered with a thin layer of paraffin wax, is mounted on a rod, A. This rod is attached to a graduated circle, B,

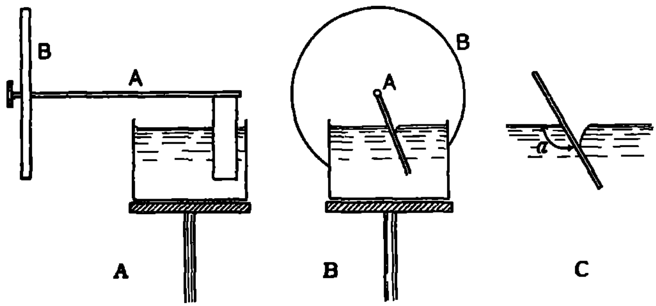


FIG. 29.

by means of which its angular rotation can be measured. The waxed slide dips in the solution whose surface tension is to be measured.

For school work the graduated circle may be replaced by an ordinary protractor, a proceeding which can be safely left to the ingenuity of the reader. Fig. 29 (C) shows the appearance of the surfaces when the waxed slide is adjusted. The angle of contact, a, can easily be measured.

The result so obtained can then be combined with the result of an observation of the depression of the same liquid in a capillary tube coated internally with paraffin wax, or with a measurement of the height of a drop of the liquid on a waxed horizontal plate. Both of these

methods of measuring surface tension, of course, involve a knowledge of α.

27. THE SURFACE TENSION OF A SOAP FILM

Rev. S. A. McDowall

A thin sliver of wood, 15–20 cm. long, is cut and a needle passed through the middle of it. This lever is pared down until it balances horizontally on the needle; the latter rests upon " knife edges " made by binding up a piece of tin into a V shape and then clamping it on a retort stand, or fixing it on a wooden pillar. Two wire trays across the V will prevent the lever from falling when the balance is imperfect.

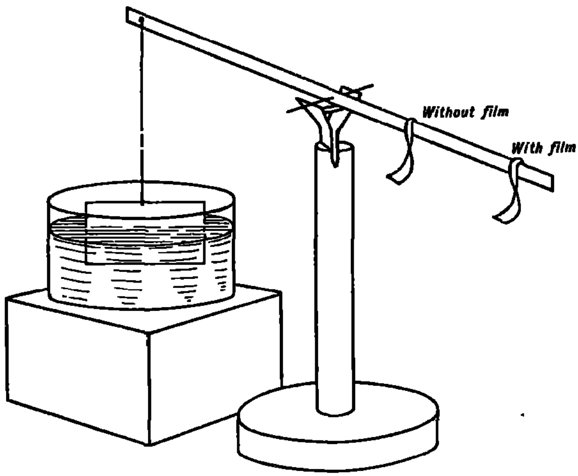


Fig. 30.

To one end of the lever a thin wire, bent so as to form a rectangle, is attached by a fibre of silk. A light counterpoise, made by cutting out an isosceles triangle with a hook at the apex, height about 7 cm., base about 1 cm., from a thin sheet of metal, bending it into an S shape, and twisting the top through a right angle to form a single

sharp edge, is attached to the lever at the end opposite to the rectangle. The latter dips into a vessel containing soap solution, and the counterpoise is slid along the lever until this balances horizontally, with the base of the rectangle just lifted from the bottom of the vessel while still dipping into the solution. The lever will not remain poised in this position if the wire is quite rectangular, but nevertheless the right position of the counterpoise can be determined to a fraction of a millimetre. A film is then formed in the rectangle and the new position of the counterpoise determined.

The positions of the counterpoise and suspending fibre are marked on the lever by means of a pencil, and moments are taken. The surface tension of the film can obviously be calculated if the dimensions of the rectangle and the weight of the counterpoise are known. The weight of the rectangle cancels out.

28. SURFACE TENSION AND THE SHAPE OF A SOAP BUBBLE

Rev. S. A. McDowall

The diagram illustrates a useful lecture-table experiment for showing an effect of lowering the surface tension of a soap film. A bent thistle-funnel is supported with the mouth vertically downwards, and is provided with a

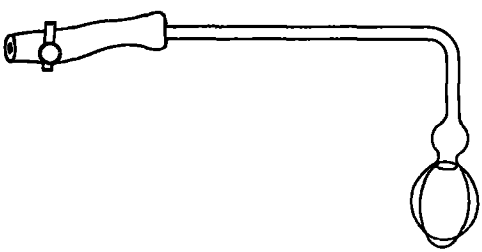


FIG. 31.

rubber tube and clip. An approximately spherical bubble is blown (about 6 cm. diameter) with a good soap solution.

A few drops of a mixture of equal parts of ether and soap solution are run on to the rim of the funnel, and the excess drop is taken off from the bottom of the bubble with the pipette. The bubble becomes ellipsoidal in shape, owing to the lowered surface tension being unable to support the weight of the film as a spherical bubble. That this is not chiefly due to the weight of the liquid added is shown by repeating the experiment with drops of pure soap solution and again removing the excess drop. As the ether evaporates, the film regains its approximately spherical form.

29. INTERNAL PRESSURE OF A SOAP BUBBLE

G. N. Pingriff

With an ordinary U-tube pressure gauge containing, say, coloured alcohol, differences in level amounting to 2 or 3 mm. are obtained with small bubbles ; the pressure gauge is connected to one arm of a T-tube on which the bubble is blown ; the difference in level can be measured accurately by a reading microscope. For larger bubbles, a more sensitive manometer, such as that described in Watson's *Practical Physics*, is better. In this case, a bent tube in the form of a very wide V is used, a small vertical pressure difference giving a considerable horizontal displacement of the liquid in the bend.

30. BOYS' DIRECTIONS FOR SOAP SOLUTION

S.S.R., (V) 20

To a clean bottle, three-quarters full of distilled water, add sodium oleate equal to one-fortieth the weight of the water, and leave to dissolve. Nearly fill up with glycerine, shake well and leave for a week in a dark place. Remove the liquid from under the scum with a siphon, add 1 or 2 drops of ·880 ammonia to every pint, and keep in a stoppered bottle in a dark place. Do not warm or filter. Glycerine greatly improves the lasting quality of the bubbles.

VISCOSITY

31. COMPARISON OF VISCOSITIES

H. W. Gilbert

A glass tube, about 80 × 3 cm., is filled with the viscous liquid and left until all air bubbles have separated out. The tube is divided into six portions of equal length by rubber bands, as shown. A thermostat surrounds the tube.

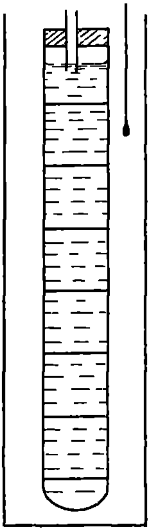


Fig. 32.

Steel ball-bearings are introduced into the top, and their fall timed over the middle two portions. For small balls, about $\frac{1}{16}$ in. diameter, the velocity is quite small and timing can be accurately done.

The method is very suitable for glycerine, olive-oil, machine oil and similar liquids.

32. COMPARISON OF VISCOSITIES

Oxford, 1921

A simple form of apparatus for comparing viscosity of gases consists in connecting the limbs of a U-tube by means of a capillary near the top. Air or other gas is forced through the capillary till the steady flow causes a fixed depression of coloured liquid in the near limb of the U-tube. Absolute values for various temperatures may be ascertained if a thermostat is employed, and if the constant of the apparatus is determined.

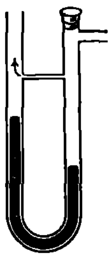


Fig. 33.

For a given rate of flow the viscosity should, of course, vary as the pressure indicated by differences in level of the coloured liquid, the exact relation being—

$$\text{V (rate of flow)} = \frac{\pi p r^4}{8\eta l}.$$

To obtain the different rates of flow of different gases, it is only necessary to collect the gas issuing from the left-hand limb of the U-tube. A more easily constructed form of the apparatus would be that indicated in Fig. 34.

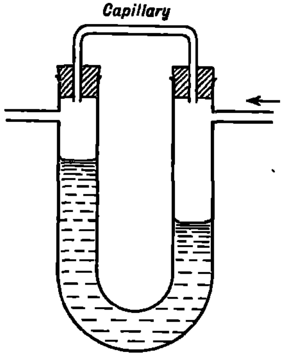


FIG. 34.

WAVE MOTION

33. A COMPACT RIPPLE TANK WITH ELECTROMAGNETIC CONTROL [1]

W. O. Clarke

The ripple tank described is of size convenient for placing on the demonstration bench, and is provided with a simple form of electromagnetic control, by means of which single pulses or continuous waves can be produced at will. The usual reflection and refraction effects can be demonstrated and, in addition, interference and diffraction patterns may be clearly shown without the aid of a stroboscope.

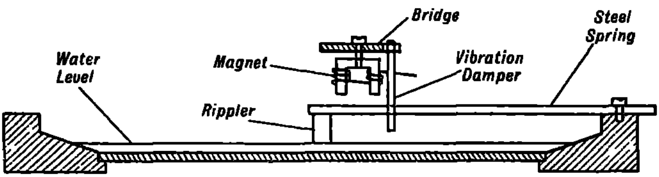


FIG. 35.

The tank itself consists of a plate-glass sheet, fitted in a wooden surround ; the surround must slope gradually to below the water level, corresponding to a shelving beach (in Fig. 35, the camber is exaggerated). The effect of the slope is to eliminate practically all reflection of ripples from the sides of the tank.

[1] Exhibited at the S.M.A. Meeting, January 1st, 1930.

The source of light may be a 100-c.p. "Pointolite," or a car headlight bulb with concentrated filament.

The water level should be about half-way up the sloping surround, but care should be taken that the "meniscus" at the water's edge is destroyed before use by running a finger round the edge, or otherwise wetting the surround.

The dimensions of the glass bottom are about 10 × 15 in., with a sloping surround about 3 in. in width and of camber about 1 in 25. The depth of water is about ¼ in. The tank is mounted on a low stand, about 1 ft. in height, which can be placed on the bench. The source of light is arranged below the tank, and the ripples are projected on a nearly horizontal screen fixed at a convenient height above. Alternatively, they can be projected on the ceiling, in which case the light is best placed at the side, with a 45° mirror under the tank to throw the light upwards. Magnification should not be too great, since the gain in size is more than counterbalanced by the loss of distinctness. A third method is to have the source below and project on to a vertical screen, using a 45° mirror above the tank.

The electromagnetic control consists of a small electromagnet, mounted on a movable bridge over the tank. The magnet attracts a flat steel spring (hack-saw blade), on the end of which "ripplers" for producing straight and circular waves are interchangeably attached. The circuit is completed by a couple of dry cells and a pear switch, so that the demonstrator can, while facing his class, produce the required effect in the tank a number of times in succession.

For reflection and refraction work, a single sharp pulse, rather than a train of waves, is the more satisfactory, so as to separate clearly the incident and reflected or refracted waves. A continuous train produces complicated interference effects which are difficult to unravel and unsuitable for demonstration to an elementary class.

A vibration damper is therefore added, consisting of a

light spring which can be pressed against the vibrator ; by its use a single pulse can be produced.

For interference work, specially light "ripplers" are used (7 gram) ; and a trembler (electric bell with gong and clapper removed, and a small terminal screwed on the clapper arm to lower the period) is placed in series with the main electromagnet. On adjusting to resonance, continuous vibration of the rippler is produced. By the use of suitable ripplers, Young's, Lloyd's and Lippmann's fringes, etc., are most clearly seen. (See Fig. 36.)

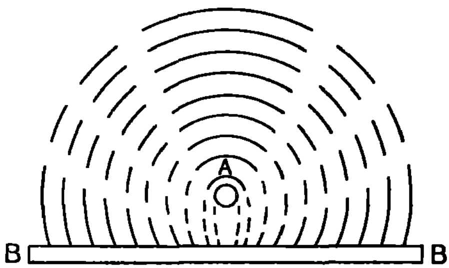


FIG. 36.

The advantage of using a separate trembler is that the necessity of having a contact-breaker in an awkward place under the main magnet is thereby avoided ; moreover, by adjusting the main magnet vertically and/or horizontally, wide variations of amplitude can be obtained, this being very necessary for good results. By the use of a two-way switch, the trembler can be cut out when desired. The vibration damper must not, of course, be in action when the trembler is used.

Note 1.—The clarity of the effects is generally diminished by using an optical system for projection ; a point source without lenses gives the best results.

Note 2.—When doing refraction experiments, with plates of glass in the bottom of the tank, the critical depth that gives the best result is most easily found by lowering the level of water in the tank till the required effect is

obtained ; for this purpose, a small siphon attached to the tank is advantageous. A cam may also be fixed to one corner of the tank for tilting it when emptying.

Note 3.—If glass or bright metal reflectors are used in the ripple tank for showing the effect of water waves, the same reflectors can afterwards be used in a smoke box for showing the effect of light waves.

Note 4.—By using two vibrating springs, of slightly different periods, a one-point rippler on each, beats can be clearly demonstrated as moving hyperbolic fringes. This is a most striking experiment.

HEAT

CALORIMETRY

34. MIXING HOT AND COLD WATER—A MODIFICATION

A. W. Barton

THIS experiment is usually performed with the idea of making the conception of heat more vivid, and depends for its success on the heat lost by the hot water being equal to that gained by the cold. It is complicated by the fact that a calorimeter has to be used to hold either the hot or cold water ; since the heat absorbed or given up by it cannot be taken into account, the amounts of heat lost and gained differ by about 10 per cent. It is unsatisfactory merely to say that this is due to the calorimeter without bringing some experimental evidence in support of the statement, for at this stage we have no idea how much heat the calorimeter will absorb or emit.

The following experiment is designed to overcome this difficulty, and is divided into two parts. First, a copper calorimeter is filled with 200 grams of cold water, whose temperature is then measured. Meanwhile, 100 grams of water are heated to a known temperature and at once added to the cold water. The final temperature is measured, and the heat lost by the hot water works out to be about 10 per cent. *greater* than that gained by the cold. Secondly, heat a copper calorimeter containing 200 grams of water to a known temperature, add 100 grams of cold water at a given temperature and measure the final temperature. This time the heat lost by the hot water is about 10 per cent. *less* than that gained by the cold. The results of these two experiments are in

accordance with the view that the effect of the calorimeter is responsible for the differences observed; in the first case, the heat lost is greater than that gained, because the excess goes into the calorimeter, whereas in the second the opposite is observed, because the hot calorimeter, as well as the hot water, gives heat to the cold water poured into it.

The following results were obtained by a class of eight pairs, four doing the experiment in the first way and four in the second:

Hot water poured into cold.		Cold water poured into hot.	
Heat lost by the hot water.	Heat gained by the cold water.	Heat lost by the hot water.	Heat gained by the cold water.
Calories.	Calories.	Calories.	Calories.
2,790	2,400	2,400	2,600
3,220	3,000	3,000	3,100
3,030	2,860	2,000	2,060
2,700	2,650	2,520	3,020

The masses of water were different in all the eight experiments, although they were always about in the ratio of 2 : 1; the temperatures were also different. But in every case the results came out as would be expected, thus showing that the heat lost by the hot water would be equal to that gained by the cold, if there were no calorimeter.

35. THICK CALORIMETERS

A. R. Marshall

These vessels are cast in, say, three different metals, iron, gun-metal and aluminium. They are about 4 in. high, with walls $\frac{1}{4}$ in. thick; the inside diameter should be the same as the ordinary copper calorimeters in use in the laboratory: the small size are 2 in. in diameter. The thermal capacity is thus very large; boiling water poured into them drops considerably in temperature, and the final temperature is very definite and steady for some

little time, thus making the reading a simple matter. Weighing to the nearest gram on a letter balance is all that is required. The specific heat of the metal is obtained by the simplest possible calculation.

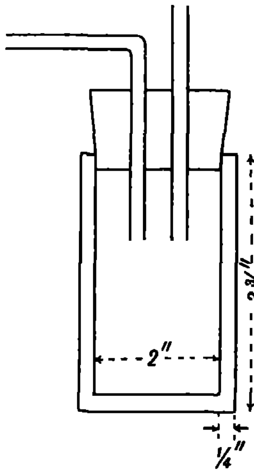


FIG. 37.

LATENT HEAT OF STEAM

Besides use for this first introduction of specific heat, the vessel can be employed for giving the latent heat of steam in a direct way, and with far better results than those obtained by the ordinary boy with the orthodox steam-trap method. A 2-in. rubber bung with glass tubes, as shown in the figure, is fitted and the whole inverted over a boiler. The outside must be lagged with a felt cover. When the steam issues freely from the outlet, a phenomenon easily noted by the boy, the vessel is at once removed and the quantity of condensed steam measured in a burette. The calculation is the simplest possible, and the method in average hands will give results between 510 and 540.

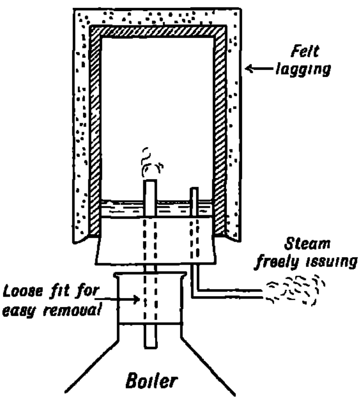


FIG. 38.

Further, if these vessels are the same internal diameter as the stock of calorimeters, the same bungs and tubing can be used with a copper calorimeter for determining the specific heat of a material on the principle of the steam calorimeter. The calorimeter with

the material is inverted, as before, over the boiler until there is a free escape of steam. In this case, of course, the amount of condensed steam must be obtained by weighing. The experiment is quite a good one for illustrating the principle of Joly's method.

The thick vessels can be cast by a local foundry for a relatively small cost. It is not necessary to have them turned up smooth—an expensive process. In the case of the iron vessels, a coat of enamel is all that is required to prevent rust.

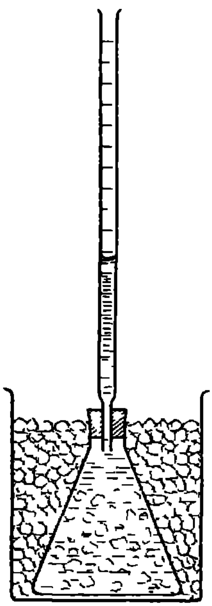


FIG. 39.

CHANGE OF STATE

36. VOLUME CHANGE OF ICE ON MELTING

E. F Thompson

Fit a 250-c.c. conical flask with a rubber stopper through which passes the drawn-out part of a "clip" pattern burette. Surround the flask with a freezing mixture and fill about one-third with paraffin oil. Add small pieces of ice free from air bubbles until the flask is full. Insert the stopper carrying the burette and add more oil in the burette. Leave for 10 minutes, or longer if possible. Transfer the flask to melting ice until no further change in volume takes place. Take this reading. Place the flask in warm water until all the ice has melted, then transfer to melting ice and take the reading when stationary. Finally, pour the mixture from the flask into a separating funnel and run the water into a measuring cylinder.

Specimen results :

Volume of Water . . .	101·5 c.c.	128 c.c.
Contraction	8·4 c.c.	10·6 c.c.

37. VAPOUR PRESSURE DEMONSTRATION

C. J. L. Wagstaff

To one neck of a three-necked Woulff's flask is fitted a thistle-funnel in which the liquid is placed and admitted to the flask drop by drop, by means of a tap half drilled. To the second neck is attached a U-tube used as a manometer. The third neck is not really necessary, but is convenient for using when the pressure is not atmospheric before starting and for drying out.

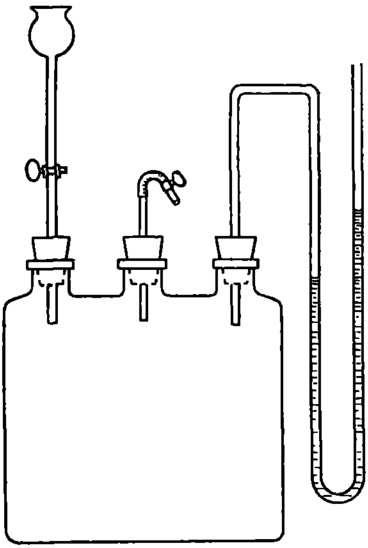


FIG. 40.

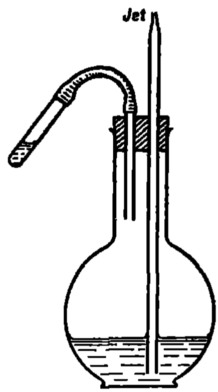


FIG. 41.

38. VAPOUR PRESSURE DEMONSTRATION

G. N. Pingriff

Another simple piece of apparatus which is not as well known as it should be is shown in the second sketch. It does not *measure* the vapour pressure, but if very slightly warmed water is placed in the flask and ether in the side

tube, the pressure is demonstrated most effectively on tilting the side tube.

39. LIQUEFACTION OF SULPHUR DIOXIDE

Cambridge, 1929

The apparatus for this is simply constructed of glass, as shown in Fig. 42, the tubes A, B and C being filled with equal volumes of sulphur dioxide, oxygen and hydrogen respectively at the same pressure and sealed off. The end of the larger tube at D is closed with a tightly fitting rubber cork, wired in and carrying an ordinary motor tyre valve. On attaching a pump and forcing air into D, the gases in A, B and C are gradually compressed, and it will be seen that the mercury in A rises more rapidly than in B and C and, finally, the gas in A liquefies. On allowing the air to escape at D, the liquid gradually vaporises, and then the mercury columns in A, B and C begin to sink.

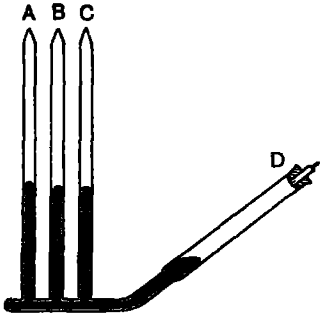


FIG. 42.

CONVECTION

40. CONVECTION CURRENTS

G. C. Bachelor

The method given below was suggested by a paragraph which originally appeared in *Conquest*.

" Nearly fill a boiling tube with benzene, and stir into it a few drops of aluminium paint (or a trace of fine aluminium powder). Place in a retort-stand clamp until the particles come to rest. The touch of a warm finger, or the approach of a lighted match, will produce currents

which can be plainly seen as the aluminium particles are carried along by them."

EXPANSION

41. LEVER EXPANSION APPARATUS

C. J. L. Wagstaff

In this instrument there is a brass tube which is fixed near one end to the case; near the other end is a stud which actuates a lever, the arms of which are in the ratio of 1 : 50. For the sake of compactness, this lever is bent through 90°, so that the free end moves over a scale which is perpendicular to the tube. By this means, the whole apparatus is held in a case 32 × 5 × 2 in. The case has windows at each end, so that the whole mechanism is visible.

To carry out an experiment, a stream of water from the tap is passed through the tube for half a minute, the

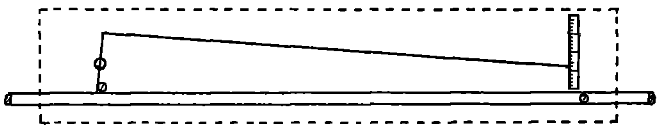


FIG. 43.

temperature is taken by a thermometer inserted at the orifice, and the position of the pointer read on the scale. Then the current of steam is passed and new readings taken.

The instrument is accurate to about 4 per cent., and is sufficiently "proof" to be sent by parcel post without special precautions.

42. COEFFICIENT OF LINEAR EXPANSION

Birmingham, 1931

A plain metallic tube has two metal plates soldered on to it. P and Q. P has a small hole drilled into it

and Q is shaped as shown. The distance between P and Q is measured by attaching a micrometer screw gauge to a stout glass tube as shown. The glass tube is bent round at one end, finishing so that it fits neatly into the hole in P. The micrometer screw gauge is clamped to the glass tube by means of a piece of wood, held in position by strong rubber bands.

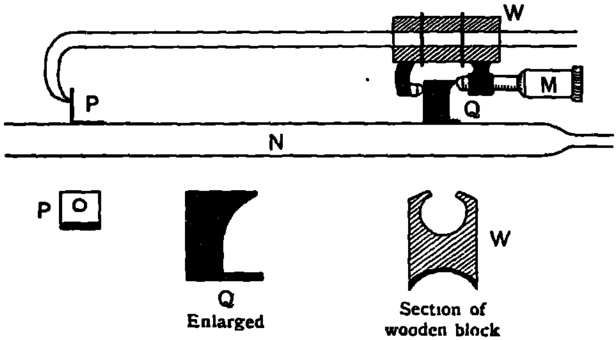


FIG. 44.

43. COEFFICIENT OF APPARENT EXPANSION

J. A. Cochrane

The following method of finding the coefficient of apparent expansion of a liquid is more easily understood by young pupils than some of the methods usually given in elementary textbooks.

A 4-oz. conical flask is filled to the brim with the liquid, and the temperature is taken. A one-holed rubber stopper, through which passes the end of a pipette, is put into the neck of the flask, and the height to which the liquid rises is marked by a piece of gummed paper, or a thin rubber band. The flask is immersed up to the neck in hot water and left until the liquid stops expanding. The new level is marked as before, and the temperature of the hot water taken. The flask is then filled with cold water to the first mark, and its volume found by pouring into a measuring cylinder; the volume of

the space between the two marks is found in the same way by pouring into a burette.

The following figures are taken from a pupil's note-book. The liquid was methylated spirit:

Initial temperature	15° C.
Final temperature	54° C.
Original volume	111 c.c.
Total expansion	4·5 c.c.

∴ Coefficient of apparent expansion = ·00104.

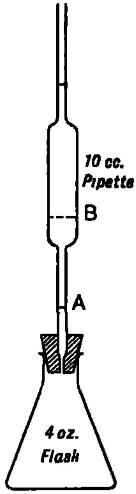


FIG. 45.

44. A SENSITIVE DILATOMETER

G. N. Pingriff

A sensitive dilatometer for studying the anomalous expansion of water between 0° C. and 10° C. may be made from a 100-c.c. measuring flask and a piece of thermometer tubing. The neck of the flask is drawn out at the mark and cut off, the widened-out end of the capillary tube being then sealed on, or an intermediate piece of tube may be inserted. A volume of mercury amounting to about 14 c.c. is then drawn in to compensate for the expansion of the glass, and the instrument is filled to about the middle of the neck with ice-cold air-free water. The filling is just a little troublesome, but once it has been done and a cork inserted to prevent evaporation, the apparatus is always ready for use on future occasions. The widened top prevents overflow of the liquid when standing in a warm room. With this apparatus, the drop in level of the liquid from 0° C. to 4° C. is really enough to measure, the exact amount depending, of course, upon the bore of the tube; with a medium-bore capillary it is about 12 mm. In conducting an experiment, *very* slow

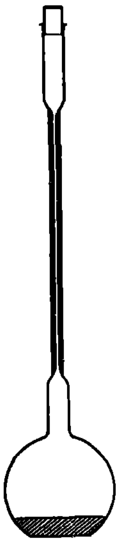


FIG. 46.

warming (several hours from 0° C. to room temperature) and very efficient stirring of the warming bath are essential.

45. EQUALITY OF EXPANSION OF GASES

F. Fairbrother

A specimen tube, 3 in. long and 1 in. diameter, is fitted with a two-holed rubber bung through which pass glass tubes A and B, as shown. The tube A is fitted with a rubber tube and a clip, and serves as a means of introducing any dry gas. The tube B is connected to a 10-c.c. pipette. The specimen tube is filled with gas while it is standing in a container in which there is ice-cold water. When sufficient gas has been passed into the specimen tube, the clip is closed and a beaker containing water is placed under the lower end of the pipette. The apparatus is now transferred into a can containing boiling water, the end of the pipette being kept under water in a beaker during the transference. When bubbles cease to pass from the end of the pipette, the apparatus is transferred back again to the ice-cold water. It is then observed that the water from the beaker rises up the pipette to a certain point on the stem, which can be marked by gummed paper. If the experiment is done with air, coal gas, hydrogen and oxygen, all carefully dried, it is found that the water rises to exactly the same mark in each case.

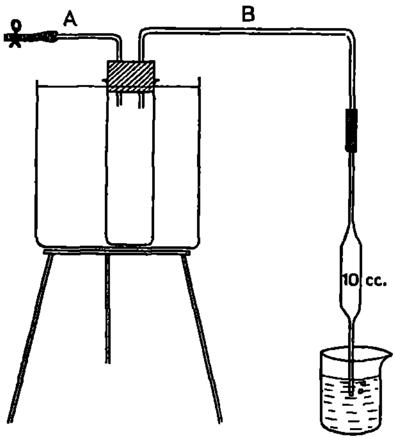


FIG. 47.

The experiment is very simple and can be performed quite satisfactorily with young children.

A specimen tube, 3×1 in., is also quite satisfactory to show that *liquids* differ in their coefficients of expansion.

46. CHARLES'S LAW

D. G. A. Dyson

A length of about 7 cm. of dry air is enclosed by a short mercury pellet in a carefully dried capillary tube, some 25 cm. long and about 1 mm. internal diameter, and enclosed at one end. It is fastened by rubber bands to a thermometer and to a stiff wire support of the shape shown (*a*). This arrangement is constructed to slip comfortably, but not too loosely, into a 6×1 in. stout boiling tube. It is surrounded by a stirrer (*b*) of wire, coiled into a loose spiral of two or three turns and long enough to reach to the bottom of the boiling tube. This is filled nearly to the brim and held in a clamp. The whole is heated gently and over the whole length with a small flame, and well

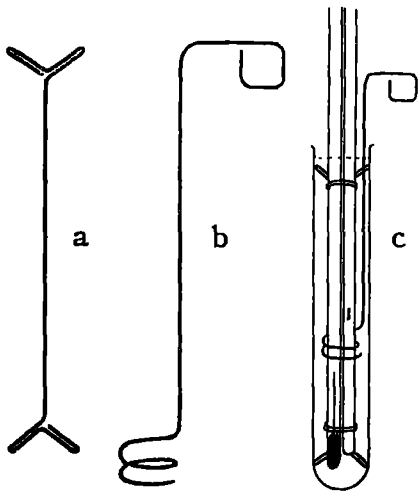


FIG. 48.

stirred. Readings of the temperature and volume should be taken about every 5°. The volume is most conveniently measured by noting the position of the lower end of the mercury pellet on the thermometer graduations themselves, and it may be found more satisfactory to arrange the closed end of the glass tube to coincide

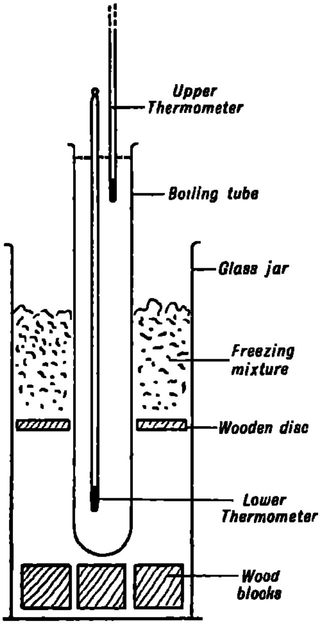


FIG. 49.

with the — 10 graduation of the thermometer instead of the 0 mark, and then add 10 to every volume reading, to allow for this.

MAXIMUM DENSITY

47. SIMPLE FORM OF HOPE'S APPARATUS

W. W. Logie

The wood blocks raise the tube clear of ice-cold water from the freezing mixture. The wooden disc supports the freezing mixture. The boiling tube is filled with tap water. The freezing mixture is packed on top of the disc.

RESULTS OBTAINED DURING MILD WEATHER IN OCTOBER 1925

A.—September 29th.		B.—October 16th.	
Lower thermometer ° C.	Upper thermometer ° C.	Lower thermometer ° C.	Upper thermometer ° C.
12·2	12·2	12	12·5
7	10	8	12
6	8·7	5	11·5
5	5	5	10·1
5	0	5	8
5	— 1	5	5
5	— 2	4·9	0
5	— 2	4·5	— 1
5	— 2	4·3	— 2
5	— 2	4·2	— 2·2
—	—	4	— 3
—	—	4	— 3

A.—Results obtained with apparatus as shown above.
B.—Results obtained with a piece of ice among the wood blocks to reduce the temperature of the air in the bottom of the jar.

RADIATION

48. A SIMPLE BOLOMETER

P. M. S. Blackett

Many instructive experiments with infra-red radiation can be carried out if suitable detecting instruments are available. Types of bolometer and thermopile will be described which are very easy to construct, have sufficient sensitivity, small thermal periods and good zeros.

The bolometer consists of two platinum strips, about 2 cm. long, 0·14 mm. wide and $\frac{1}{100}$ mm. thick. The strip

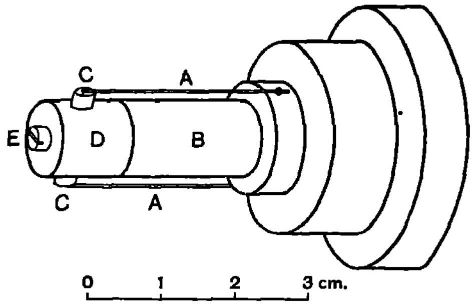


FIG. 50.

was rolled by Messrs. Pye, Granta Works, Cambridge, from No. 48 S.W.G. platinum wire. The strips AA (Fig. 50) are soldered at one end to a collar on the copper or brass rod, B, and at the other to two brass screws, CC. These screw into a short ebonite cylinder, D, forming an extension to the metal rod and screwed to it by a screw, E. A light brass case, not shown, fits over the strips. Opposite one strip is a slot so that radiation can fall on one strip, but not on the other. The strips, which have a resistance of about 0·8 ohm each, are blackened over a camphor flame. Three flexible wire leads are attached to the metal rod and to the two screws, CC. The two strips can be connected to two 1-ohm ratio arms, to form a Wheatstone bridge. If a current is run through the bridge, a balance being obtained by shunting one arm,

the galvanometer will be deflected when radiation falls on one of the strips. The sensitivity obtained with about 150 milliamperes going through the bridge and a galvanometer with a sensitivity of about 2 mm. per micro-volt, is sufficient for many purposes. For instance, a blackened cube of 100 sq. cm. face, kept at 100° C. and placed 30 cm. away, will give a deflection of 50 mm.

With this instrument it is possible not only to detect radiation, but to measure its absolute value, and so to find, for instance, Stefan's constant or the solar constant.

The method consists in finding how much electrical energy has to be dissipated in the strip to raise the temperature of the strip by the same amount as when the radiation is falling on it. To do this it is first necessary to plot the increase of the resistance of a single strip, measured by balancing with a shunt, against the square of the current in the bridge. Since the heat loss from the strip and the change in its resistance are both proportional to the rise of temperature, the relation should be linear; from the slope can be calculated the energy required to change the resistance a given amount. It is next necessary to find the galvanometer deflection for a given change in the strip resistance. This can be done by changing the value of the shunt resistance and observing the resulting galvanometer deflection. Combining these two results, we find the galvanometer deflection for a given energy dissipation in the strip—and therefore for a given radiation energy received by the strip.

Note.—In giving permission for republication, Mr. Blackett suggests that the construction of the bolometer might be improved. The model here described had simplicity as its main aim; it is consequently not very rigid.

49. A SENSITIVE THERMOPILE

P. M. S. Blackett

The method of constructing the thermopile is that described by Wilson and Epps (*Proceedings of the Physical*

Society, London, p. 326, 1920). It avoids the difficult operation of soldering fine wires or strips. A brass or copper frame (A, Fig. 51) is made of the shape shown, and is then coated with shellac varnish. On it are wound several turns of constantan strip, 0·3 mm. broad and $\frac{1}{100}$ mm. thick, rolled from No. 44 S.W.G. constantan wire. The frame is of such a shape that half of each turn lies flat against the back of the frame, while the other half is stretched free between the two ridges. The frame is then immersed, with the strips vertical, in a copper sulphate solution and a light copper coating deposited on *half* of the winding. The result is that one row of junctions is formed at BB between constantan and copper-constantan, and another row at the back of the frame. Owing to the widely differing conductivities of the two metals, the coppered-constantan strip acts almost like a pure copper strip. A thermopile with many junctions can thus be constructed without any fine soldering. To get a good deposit of copper, it is advisable to use two fair-sized copper plates as electrodes. The frame is then half immersed and the winding connected to the cathode. The thermopile is fitted on to a brass disc, C, and a cover (not shown) fitted, with a hole to allow the radiation to fall on the junctions, BB. With a winding of 13 turns, such a thermopile has a resistance of 21 ohms, and will give a deflection of 250 mm. under the same conditions as were mentioned in connection with the bolometer. The thermopile is, therefore, about five times as sensitive.

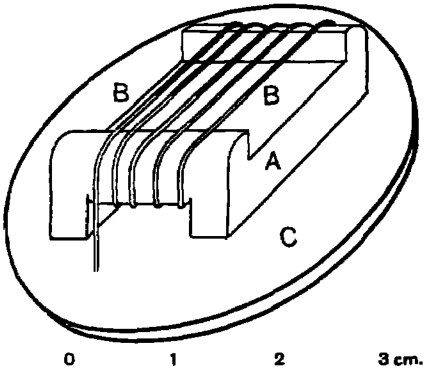


FIG. 51.

It can, however, be used only for relative and not for absolute measurements.

50. RADIATION LAW FOR AN ELECTRIC LAMP

F. G. Mee

This experiment consists of an accurate determination of the way in which the resistance of an electric lamp varies with the current passing through it. It may be shown (see *School Science Review*, No. 46, pp. 157–9) that the figures so obtained can be made to yield the index of the power law expressing the radiation from the filament as a function of the absolute temperature.

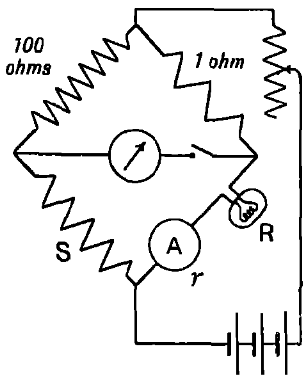


FIG. 52.

The usual method for lamp resistance—ammeter and voltmeter—is scarcely accurate enough. The following bridge method may be successfully used.

A small electric lamp, preferably rated at about ½ amp. and 4 or 6 volts, is connected in the circuit shown.

The 1-ohm coil must be capable of carrying the current required by the lamp without appreciable heating. The coil S and the 100-ohm coil may conveniently be the "variable" arm of a P.O. box and one of the ratio arms, respectively. The battery should consist of one accumulator cell more than is necessary to supply the normal voltage for the lamp, and it should be connected to the bridge through a sliding rheostat.

Set the resistance arm of the box at 1,000 ohms or more, and adjust the rheostat until the lamp is carrying its full-rated current, indicated by the ammeter, A. Then balance the bridge exactly by altering the P.O. box arm until the galvanometer shows no current. With a good table

galvanometer, it is possible to balance to an accuracy of 1 ohm. Note the balancing resistance and the current through the lamp at the instant of balance. Now set the arm, S, at about nine-tenths of its former value, and alter the lamp current by means of the sliding rheostat until a balance is approached. Leave the rheostat fixed at this value and carry out the exact balance by altering S once again. Having noted the balancing resistance and the current at the instant of balance in this case, now set S at about eight-tenths of its original value and repeat the operations, and so on down to about one-tenth of the original value. In this way a series of values of balancing resistance and current is obtained, and they are spaced at roughly equal intervals of resistance.

The balancing resistances so determined are not just those required to balance the resistance of the lamp alone, since the ammeter has added a constant term to the resistance of the arm. To find a correction for this, remove the lamp completely from the arm and join across the space it occupied, so that the ammeter alone is in that arm. Adjust the rheostat so that about 1 amp. is flowing, and balance to the nearest ohm as before, keeping the ratio arms exactly as formerly. This measurement gives the value of the term to be deducted from the total balancing resistance in order to obtain the resistance necessary to balance the lamp alone. The resistance of the lamp is $\frac{1}{100}$ of this last quantity, and therefore can be calculated in each of the measured cases.

For specimen results and the deduction of the power law index from them, see *School Science Review*, No. 46, pp. 159–61.

SPECIFIC HEAT RATIO

51. CLEMENT AND DESORMES' EXPERIMENT

E. Nightingale

A foot length of $\frac{3}{4}$ or 1 in. soft glass tubing is taken; the ends are softened in the blowpipe flame, and one is

neatly finished with the carbon cone. A hole is blown about 4 in. from one end, and a side piece, A, of ordinary tubing is sealed on. Another hole is blown on the opposite side about 4 in. farther down, and another side piece, B, fitted (Fig. 53).

An ordinary empty carboy is obtained in the usual lattice case with straw packing, which should be left on. The packing is shown dotted in Fig. 54. A hole large enough to hold the wide tube is made in the cork of the carboy. After about a beaker of concentrated sulphuric acid has been poured in, the cork and joints are made

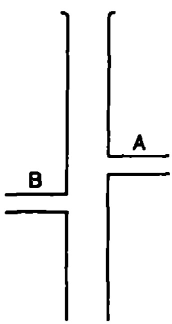


FIG. 53.

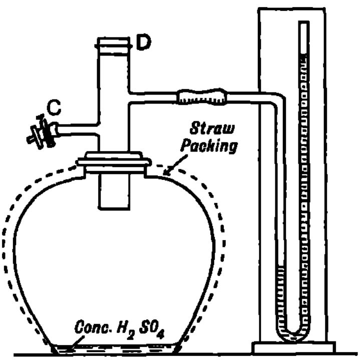


FIG. 54.

air-tight with "heel ball." This is obtained from any cobbler, and is a most useful substance in the laboratory.

To the lower tube is fitted a short piece of pressure tubing, in which is screwed a bicycle pump connector. A screw-clip, C, is also attached. To the upper tube is attached, by means of pressure tubing, a manometer containing oil.[1] This should be sufficiently long to enable a "head" of 80 cm. to be obtained. A rubber bung, D, completes the apparatus.

To perform the experiment, a bicycle pump is con-

[1] The oil should be of the non-volatile variety: turpentine is unsuitable; castor oil will do.

nected to the lower tube, C is opened and air is pumped in until the " head " of oil is about 70–80 cm. The clip, C, is then closed and the apparatus allowed to stand 15 or 20 minutes to attain the air temperature ; the " head " is then carefully read. From this and the barometer, the initial pressure, P, is found.

The bung, D, is now quickly taken out and replaced after an interval of 1 second. The expansion is adiabatic and the air is cooled. Immediately after the expansion it is at atmospheric pressure, P. The manometer becomes steady after another 15 or 20 minutes, and the new pressure, P_2, is worked out.

[Boys working with this apparatus obtained for air $\gamma = 1{\cdot}40,\ 1{\cdot}43,\ 1{\cdot}41$.]

52. CLEMENT AND DESORMES' EXPERIMENT

E. W. E. Kempson

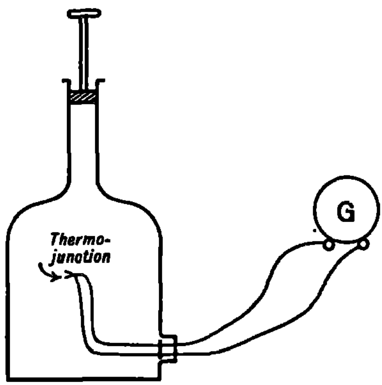


FIG. 55.

Diameter of pump	= 5·1 cm.
Stroke of pump	= 34·5 cm.
Volume of pump	= 706 c.c.
Volume of bottle	= 23,320 c.c.
Total volume	= 24,026 c.c.

Calibration of galvanometer and thermo-junction :

Temperature.	Deflection.
27·1°	119 div.
21·1°	160 ,,
6°	41 ,,

ONE DIVISION ON GALVANOMETER CORRESPONDS TO 0·146° C.

Adiabatic Compression

Plunger up:
Vol. = 24,026 c.c. Temp. = 18° C. Gal. 108·5 div.
Plunger down :
Vol. = 23,320 c.c. Gal. 82·5 div.
Change of temp. = 26 × ·146 = 3·8° C.
Final temp. = 294·8° A.
But, for adiabatic compression,

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

where T_1 and T_2 are absolute temperatures corresponding to volumes V_1 and V_2,

$$\text{whence } \frac{294{\cdot}8}{291} = \left(\frac{2403}{2332}\right)^{\gamma-1}$$

giving $\gamma = 1{\cdot}43$.

LIGHT

53. A NARROW BEAM OF LIGHT

F. A. Meier

A REMARKABLY fine beam of light may be obtained by the simple device of using a long-focus lens (about 70 cm. double convex) in an oblique position. Reference to Fig. 56 will show the most convenient arrangement.

The slit is pinned to the edge of a drawing board (end view, Fig. 57) with two drawing pins, and a 4-volt ·3-amp. Philips lamp, with straight fine spiral filament, is set

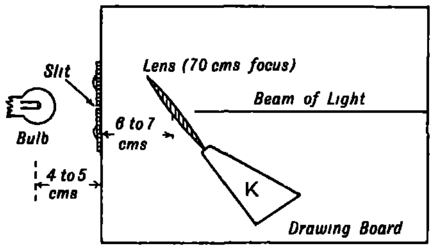


FIG. 56.

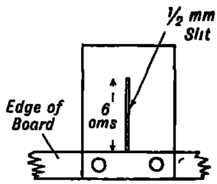


FIG. 57.

up 4–5 cm. from it. The long-focus lens is placed 6–7 cm. from the slit in an oblique position, and is held in a saw-cut made in a prism-shaped block of wood, K. The object of having a block of this shape is that none of its corners shall interfere with the beam of light. The lens should be about 2 cm. above the paper on the board, and the bulb rather higher, so that the light shines in a slanting direction downwards. The best height for the bulb, as well as the various distances and obliquity of the lens, are found by trial.

With such an arrangement, a narrow beam a foot long can be obtained for carrying out many of the elementary

experiments on reflection and refraction. The room need be only partially darkened, leaving sufficient light by which to draw.

Messrs. Philip Harris supply the small lamp-holders on stands, and Halford's Cycle Shops generally keep the small 4-volt gas-filled lamps in stock. The cost is about 9*d*. or 10*d*.

Undoubtedly the more powerful motor lights working on 12 or 14 volts give far more satisfactory and beautiful results. To avoid having to use accumulators, it is best to run a small transformer from the light mains. Very neat little transformers are made by Messrs. Pye & Co. Four pairs of leads may be taken from the secondary. It is thus possible to work four lamps from one transformer and to obtain eight beams of light. Messrs. Pye make transformers to a given specification.

The experiments are far more instructive if the under-surfaces of the prisms and blocks of glass are ground so as to show the path of the beam of light inside the glass.

54. LIGHT BEAMS FOR ELEMENTARY PRACTICAL OPTICS IN DAYLIGHT

A. R. Marshall

The essential part of the method is the use of the straight spiral filament car headlight, as in experiment 53. For the most striking results, it is best to have the powerful 36-watt 12–14-volt type. The lamp is mounted in a vertical downward position in a suitable tin (a 50 Gold-Flake tin does very well), with two wide apertures, ½ in. by about 1¼ in., diametrically opposite each other. A short focus lens, in a simple holder of bent tin which allows it to sit well down on the paper, focuses a parallel beam inclined slightly downwards so as to cut the paper at a small angle. A similar lens on the other side provides a second beam for another pair of pupils. The wide beam can then be cut up into several narrow beams (three is a convenient number), which are sufficiently parallel for all

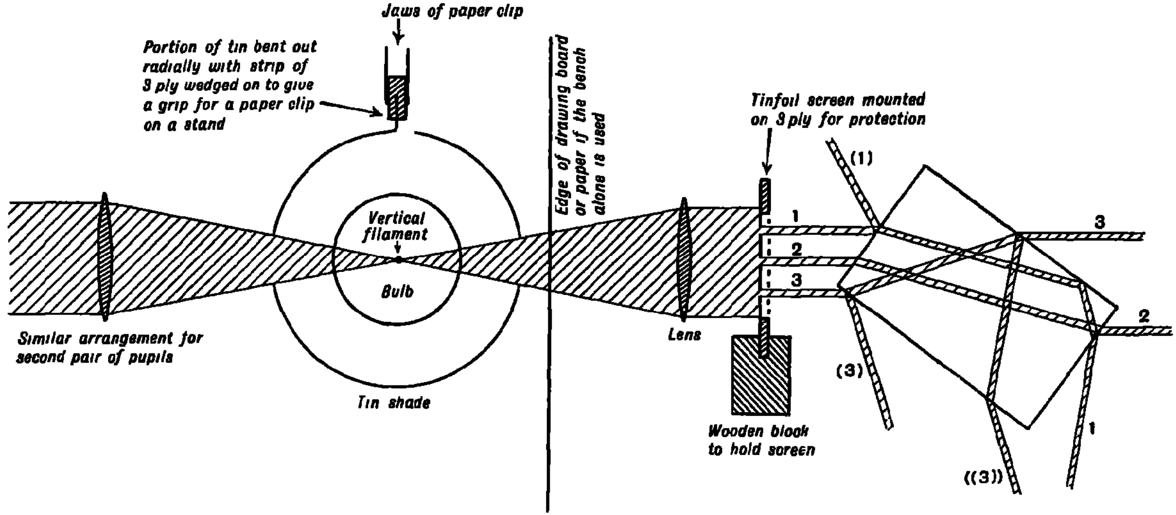

Jaws of paper clip
Portion of tin bent out radially with strip of 3 ply wedged on to give a grip for a paper clip on a stand
Vertical filament
Bulb
Tin shade
Similar arrangement for second pair of pupils
Edge of drawing board or paper if the bench alone is used
Lens
Tinfoil screen mounted on 3 ply for protection
Wooden block to hold screen
1
2
3
(1)
(3)
((3))
3
2
1

Fig. 58.

elementary purposes. This can be done by three slits in a tinfoil screen, mounted on cardboard or three-ply, and supported by a small wooden block. (Tinfoil out of a tea-chest is good stuff.)

It is quite a simple process to roughen the ordinary glass slabs and prisms on one side by rubbing with coarse emery powder and turpentine for a few minutes on a glass slab. The path of the light in the glass is then easily visible. Blocks which have been sand-blasted and with small bevels are, of course, better, and are supplied by firms. With such a lamp the beams are easily seen in a room without any darkening of the windows. The figure shows the general arrangement.

The study of colour is frequently left to the end of the course, and then takes the form of a demonstration lesson only. The lamp suggested has a filament which is sufficiently intense and narrow to produce a fairly pure spectrum by using a single lens and prism without a slit, and the brilliancy is such that it will show up on a vertical screen even when facing the windows. Thus it is possible for quite elementary classes to study the composition of white light in the practical periods. Each pupil can make his own spectrum, and by using the cheap theatre flood-light gelatine filters mentioned in No. 59 (p. 71) (some of which are much purer spectrally than the usual coloured glass), he can study various absorption effects.

It is an easy matter to set up the same beam apparatus in a vertical plane for demonstration purposes (see Fig. 58B). The lamp is placed with its filament horizontal, and the lens, slits and glass blocks or mirrors are fixed on the face of a drawing board, placed vertically. For holding the blocks, etc., to the board, a strong spring on the end of a 2 B.A. bolt suffices well enough. The bolt is slipped through various holes in the board and jams under the action of the spring. Old trouser clips make very good springs.

The question of the power for lighting these lamps may be a difficulty. Undoubtedly the best method, where the

supply is A.C., is to have a step-down transformer to give the necessary low voltage. Such transformers are available. Failing this, there is no alternative but to connect the seven or eight lamps required for a class of thirty in series with a resistance, moving-iron ammeter (if A.C. supply) and the mains.

A cheap resistance can be constructed out of the helical springs sold as curtain supports. Four 9-ft. lengths,

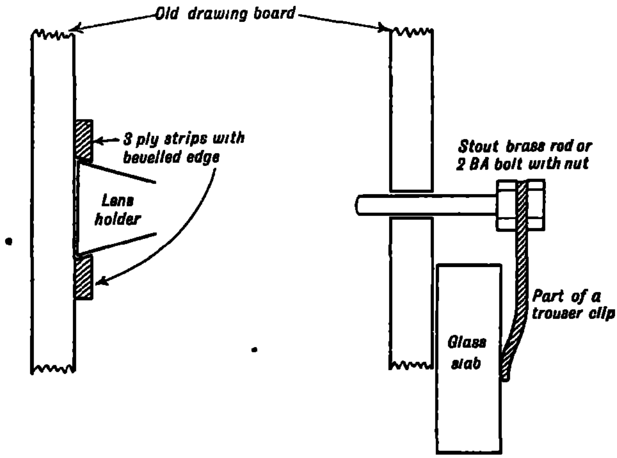


FIG. 58B.

slightly stretched to open the coils, wound on a piece of uralite, provide a resistance of about 70 ohms when hot. For single-lamp working, such a resistance can be safely put across the light mains as a potentiometer and tappings taken off to the lamp by means of crocodile clips (sold by wireless dealers). For series working of several lamps, a portion of such a resistance can be used.

55. "THE OPTICAL SMOKE-BOX"

W. O. Clarke

This consists of a box (Fig. 59), completely closed, of which one side is made of window glass ; the dimensions

of the box are about 2 ft. × 6 in. × 6 in. (or larger). The interior of the box is blackened, and one end is provided with a circular glass window about 1 in. in diameter, which can be covered by a cardboard screen pierced with various holes and slits. Light from an arc-lamp, rendered parallel by a single convex lens, falls on the window. The beam passing through the window is made visible inside the box by filling the latter with smoke. A door in the back of the box allows lenses, prisms, mirrors, etc., to be inserted in the path of the beam, and arrangements

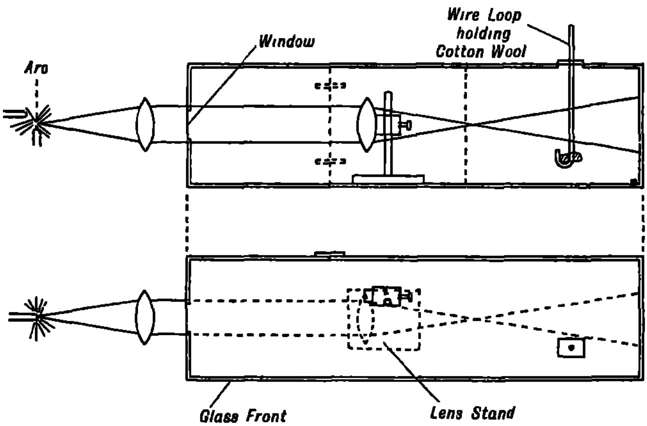


FIG. 59.

are provided for giving a small range of motion to the stands carrying lenses, etc., without opening the box.

Smoke is conveniently provided by means of a small piece of cotton waste, held inside the box in a loop of wire, or tobacco smoke may be used. The smoke cloud is rendered stable and uniform by means of an air blast from a rubber bulb attached to the box. (A good bellows may be improvised from a penny Chinese lantern.) It is not necessary to have a completely darkened room ; the smoke cloud lasts for about one hour without requiring renewal. For further particulars, see *The Journal of Scientific Instruments*, Vol. IV, No. 4, January 1927.

Among the many experiments that can be demonstrated, the following may be specially mentioned:

Diffraction by a Grating.—A Thorp replica grating (14,000 lines to the inch) is mounted in the box, and a single beam made to converge on the grating. The first and second orders of the transmitted and reflected spectra are visible as coloured beams in the smoke.

Polarisation.—The beam entering the box is made parallel and is polarised by means of a Nicol prism. A pile of plates (half a dozen microscope slides) is mounted in the box, and adjusted so that the polarised beam falls on it at the polarising angle. If the Nicol prism is rotated till the reflected beam is at its brightest, a further rotation of 90° causes complete disappearance of the whole reflected beam.

Complementary changes in the intensity of the transmitted beam are of course observable.

CAMERAS

56. PIN-HOLE CAMERA FOR SOLAR PHOTOGRAPHY

B. M. Neville

A metal tube about a yard long and $1\frac{1}{2}$ in. in diameter, originally intended as a map case, has a pin-hole through the cap at one end, and the other end is pushed firmly into a hole in the lower portion of a piece of wood about 6 in. square and $\frac{1}{2}$ in. thick. This board is hinged to a weighted base which, when the camera is in use, rests upon a table, while the upper end of the tube is supported by a movable stand, the whole arrangement being adjusted before each exposure so that no shadow of the tube is cast upon the board, thus ensuring that the camera is pointing directly towards the sun. A disc of cardboard is mounted on the end of a short wooden rod which, after being passed through a hole in another piece of card, is fitted with a pointer, the latter serving both to turn the

disc and to indicate its position. This device constitutes a paper holder and, after a disc of gas-light paper has been fastened to the cardboard disc, it is attached to the back of the board forming the end of the camera, the whole being made light-tight by binding the edges together with strips of gummed paper. The paper holder is in such a position that the rear end of the camera tube comes near the circumference of the disc, and so, by rotating

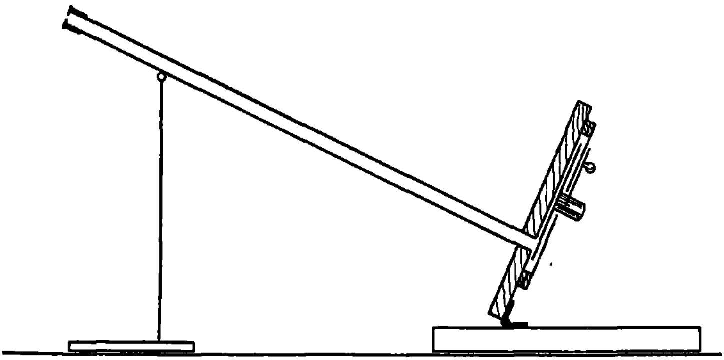


FIG. 60.

the latter, a series of photographs is obtained in a ring on one sheet of sensitive paper. The pictures obtained are about $\frac{1}{3}$ in. in diameter, and, though pin-hole definition is not very sharp, the device enables one to obtain a pleasing record of the progress of a solar eclipse.

57. A CAMERA FOR ASTRONOMICAL OBJECTS

G. N. Pingriff

The great defect of photographs of the sun and moon as taken by ordinary cameras is that the image obtained is so disappointingly small. To overcome this difficulty by means of improvised apparatus is not impossible, but requires some little ingenuity in the matter of suitably binding together the telescopic apparatus and the camera. This has been recently successfully accomplished by

mounting an ordinary half-plate camera on a tripod with a small prismatic pocket telescope—equivalent to one-half of a $\times 8$ pair of field glasses. The system was used to take photographs of an eclipse of the sun, and the illustration[1] is printed to almost the exact size of the original negatives, which indicates that the equivalent focal length of the lens combination used was about $10\frac{1}{2}$ ft. Thus :

$$\frac{1{\cdot}1 \text{ in.}}{10\frac{1}{2} \text{ ft.}} = \frac{1{\cdot}1 \times 180}{10{\cdot}5 \times 12 \times 3{\cdot}14}\,^{\circ} = \text{approx. } \tfrac{1}{2}^{\circ},$$

which is the angle subtended by the sun.

The aperture used was estimated to be not greater than *f*. 170, and the exposure given in each case was $\frac{1}{4}$ sec., which proved to be just about correct in the third, but rather too much in the second and first, of the series. The exposures were made at approximately 3.20 p.m., 3.30 p.m. and 3.45 p.m. The chief difficulty experienced, as was to be expected, lay in the fact that the image was steadily creeping over the plate, making a new alignment of the apparatus necessary for each exposure. In spite of these difficulties, three excellent negatives were obtained, far better than would appear from the reproduction, before the sun was finally lost in the clouds. Lantern slides have been made from the negatives, and these are of considerable interest in astronomy lectures.

COLOUR (see also *Dispersion* and *Spectrum*)

58. DYED GELATINES

A. F. Kitching

Dyed gelatine suitable for colour filters may be obtained from Ilford, Ltd., or Kodak, but for those who wish to make their own gelatines the following details may be helpful.

Emulsion gelatine is thoroughly soaked in several changes of distilled water, then melted down and filtered

[1] S.S.R., No. 24, facing p. 272.

in a water-jacketed funnel at about 100° C. The gelatine for coating slides should be about 6 per cent. strength in cold weather to 8 per cent. in hot weather. Dyed gelatines are then coated on clean warm glass, using 1 c.c. solution per 10 sq. cm.: the glass and gelatine solutions should be warm only, not hot: the glass must be accurately level until the gelatine has set. The dye composition of the six chief colours is given as weight of dye in grams per 100 c.c. of gelatine solution.

Primaries.

Red: Rose Bengal 0·5, Flavazine T 0·1.
Green: Patent Blue A 0·02, Filter Blue Green 0·03, Naphthol Green 0·03, Flavazine T 0·1.
Blue: Patent Blue A 0·03, Filter Blue Green 0·06, Xylene Red 0·08.

Complementaries.

Sky Blue: Patent Blue A 0·03, Filter Blue Green 0·03.
Magenta: Xylene Red 0·1, Rose Bengal 0·05.
Yellow: Flavazine T 0·2.

It is important that the dyes should be chemically pure; those of commercial quality are quite unsuitable in many cases.

The spectral cut of the above colours is as follows:

Primaries.

Red: Red end to 5,900 A.U.
Green: 5,900 to 4,900.
Blue: 4,900 to violet end.

Complementaries.

Sky Blue: (Minus Red) 5,700 to violet end.
Magenta: (Minus Green) Red to 6,000 and 4,900 to violet.
Yellow: (Minus Blue) Red end to 5,100.

The three primaries are useful for a rough analysis of the

colour of coloured glasses, such as dark-room safe lights, e.g. many so-called ruby glasses transmit blue and are therefore photographically unsafe. By superimposing the complementaries on one another, the principles of three-colour printing and the subtractive synthesis of colours may be illustrated. By superimposing the primaries on the complementaries, the additive synthesis of colours as in screen-plate colour photography may be illustrated, e.g. that yellow = red + green.

59. COLOUR FILTERS

E. G. Savage

The Kodak Co., Wratten Dept., Kingsway, London, W.C., supplies excellent filters which are, however, too expensive for *class* use. Mounted as lantern slides, they are 2*s*. each; unmounted, 1*s*. 6*d*. The most useful filters for the teaching of colour are Nos. 29 (red), 58 (green), 46 (blue), 12 (a compound filter transmitting yellowish-red and green), 32 (magenta, or red plus blue), 44 (peacock blue, or green plus blue). Nos. 70–75, a set of monochromatic filters, are also of value, but, on account of the smaller amount of light transmitted, are less effective than the others mentioned. No. 73, however, a monochromatic yellow, is essential for comparison of its properties with the compound yellow, No. 12.

Colour Filters for Class Use.—The Strand Electric Co., 19–24 Floral Street, Covent Garden, London, W.C.2, and T. J. Digby, Ltd., 12 and 29 Gerrard Street, W.1, supply colour filters in large sheets, 22 × 17½ in., the former at 8*d*. per sheet, the latter at 10*d*.

The most useful numbers are:

	Strand Electric Co.	Messrs. Digby.
Red	No. 14	No. 8
Green	,, 24	,, 15
Blue	,, 20	,, 24
Yellow (red plus green)	,, 1	,, 1
Magenta (red plus blue)	,, 12	,, 9
Peacock blue (green plus blue)	,, 15	,, 11
Purple (red plus violet)	,, 25	,, 22

Ordering should be done by numbers, since the names of the colours given by the firms do not always agree with the names used in this book.

60. MOUNTING COLOUR FILTERS FOR LANTERN WORK

E. G. Savage

The filters are best used mounted as lantern slides, but it is inconvenient to have to fumble for the appropriate filter in a dark room. Fig. 61 shows a device which enables a lecturer to take each filter quickly in rotation.

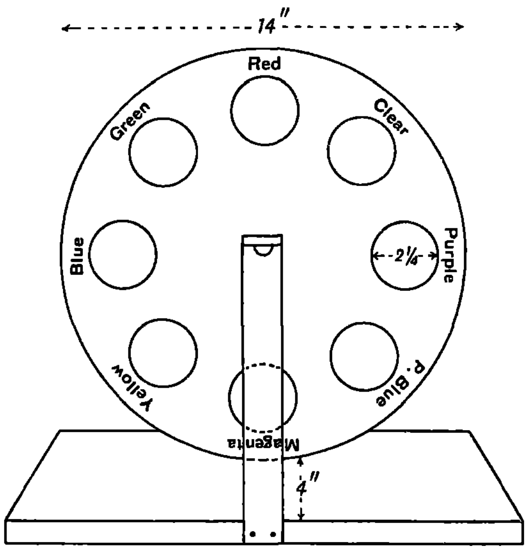


FIG. 61.

It consists of a wheel, of the dimensions shown, made of two pieces of three-ply wood, with 8 circles of $2\frac{1}{4}$ in. diameter. Seven filters are arranged as shown, and the eighth space is occupied by a clear-glass slide, so that a comparison can readily be made between the whole spectrum and those portions transmitted by the filters. The wheel costs less than 3*s*. to make.

61. COLOUR MIXING—THE "SPECTRUM GATE"

E. G. Savage

The usual lantern, condensing lens, slit, parallelising lens and prism are set up to produce a spectrum on a "distant" screen. Close to the prism, where the rays emerge, sorted out into colours, is placed an iris diaphragm. (A series of graduated holes on a piece of cardboard will serve.) A second convex lens is placed at its focal distance (8 in. is convenient) from the diaphragm, and this lens does two things: (*a*) it focuses a small but intense spectrum at a nearer plane, G, Fig. 62; (*b*) it forms a white image of the diaphragm on the distant screen. At the position G is placed a brass or wooden strip with a rectangular aperture in it, which may conveniently be termed a "spectrum gate." Any portion of the sharply focused spectrum may be cut off by hanging small strips of metal in the appropriate position. The colour of the patch on the screen will then change from white to a colour which is complementary to those cut off by the brass shutters on the gate.

62. COLOUR MIXING—SKEW PRISMS

E. G. Savage

A still more instructive part of the experiment is to substitute for the brass shutters, or for some of them, "skew" prisms. A skew prism differs from the ordinary prism in having two refracting angles, and may be made by cutting a strip from a small angle prism, as shown in Fig. 62 (*b*). The prisms from which these are cut (any competent glazier will do this) should have a refracting angle of from 3·5° to 5°.[1] The writer is indebted to Mr. Johnson for approximate dimensions. Using lenses

[1] Prisms of this kind, with angles varying from ½° by ½° to 20°, may be obtained very cheaply (about 10*d.* to 1*s.* 6*d.*) from Messrs. Gowllards, Morland Road, Croydon. This firm deals only with the trade, but doubtless the usual school supply firms would act as intermediaries. A method of grinding skew prisms is given in No. 212.

of the focal lengths given in the diagram, suitable sizes for these skew prisms to hang in the red, green and blue are 20 × 13 mm., 20 × 9 mm. and 20 × 6 mm.[1] When these are hung on the gate, in the position of the three primary colours, the rest of the spectrum being cut off by metal shutters, three images—red, green and blue—appear on the screen at the corners of a triangle. On enlarging the diaphragm, they overlap. When blue and red over-

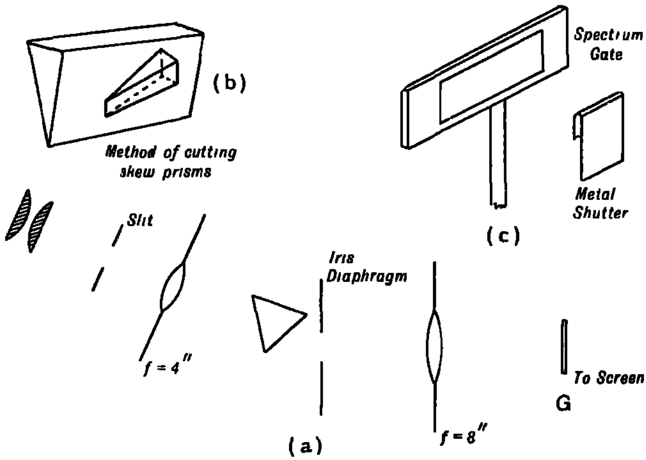


FIG. 62.—Copied by permission from *Lecture Experiments in Optics*, by B. K. Johnson (Edward Arnold, 8*s.* 6*d.*).

lap magenta is produced ; when green and blue overlap we get peacock blue, and most striking of all for those who do not know what to expect, when red and green overlap yellow is produced. When all three overlap the colour is white. The writer finds it convenient to reproduce a record of this result in permanent form by drawing it in colour on cardboard, making the circles as large as possible and labelling the exhibit "Mixture of coloured lights."

[1] It is wise to fit up the apparatus first and then to cut the prisms to fit the different colours on the gate.

63. COLOUR MIXING—THREE LANTERNS

E. G. Savage

Three lanterns, each carrying, say, a red, green and blue filter, might be used, but in practice three lanterns are not generally available! A simple substitute may be readily contrived. Fig. 63 shows a small home-made projector, consisting of a wooden box (oak), carrying a lamp bulb (100–150 watts), in front of which is a partition, in which is a circular hole. In front of the partition is a holder to carry a filter, mounted as lantern slide. On

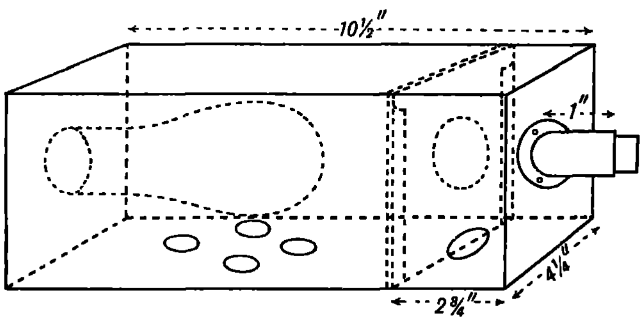


Fig. 63.

the front of the box is a brass tube, carrying a lens combination of about 2·5 in. to 3·5 in. focal length. The writer uses three of these to project three coloured images on the screen, which may be made to overlap as desired. Holes are drilled in the bottom and in the lid (which is not shown in the figure), to prevent any possible overheating. The holes in the lid are baffled by a metal plate, to avoid the escape of stray light into the room. Originally it was intended to make up the lens combination, but it was found possible to buy it much better and cheaper.[1] As a result, the three projectors, together with the lamps, cost only about £2.

[1] Apparently the cinema industry has changed its method of projection. Consequently, excellent lens combinations are available at from 5*s*. to 10*s*. Messrs. Broadhurst, Clarkson & Co., 63 Farringdon Road, London, E.C.1, have still a number of them.

64. COLOUR MIXING—THE COLOUR TRIANGLE

E. G. Savage

Another method is that of the colour triangle, shown diagrammatically in Fig. 64. The triangle consists of a stout board, 50 cm. each side, carrying three lamp houses, made of sheet tin, which should be large enough to hold a 100–150-watt lamp. These lamp houses, being carried at right angles to the triangle, are shown only in plan in the figure. In front of each is a slot to carry the usual lantern-slide filter, a red, green and blue being generally used.

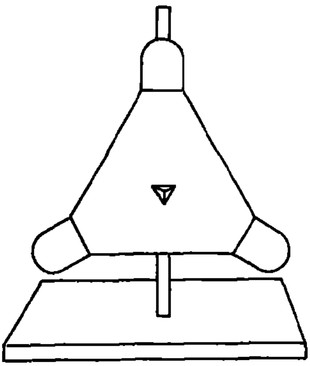


FIG. 64.

The triangle is covered with a sheet of white cardboard with a matt surface, and at its centre is placed a tetrahedron (about 2 in. base and 2 in. high), also painted white, which may be revolved on its axis. The mixture of colours is seen in two ways: (*a*) each side of the tetrahedron may be illuminated by the light from any of the two filters, and according to the angle at which it is placed, relative intensities may be adjusted. Thus, using the red and the green filters, by revolving the tetrahedron slowly, the colour of any face may be made to change from red, through reddish yellow to yellow, greenish yellow and green, the colours of the other sides changing correspondingly. (*b*) The shadow cast by the tetrahedron by one lamp is illuminated by the other two. Three shadows are therefore cast, one from the red, one from the blue, and the other from the green. These, being illuminated by the other two, are peacock blue, yellow and magenta respectively. It is a little difficult with this apparatus for these to be easily distinguished

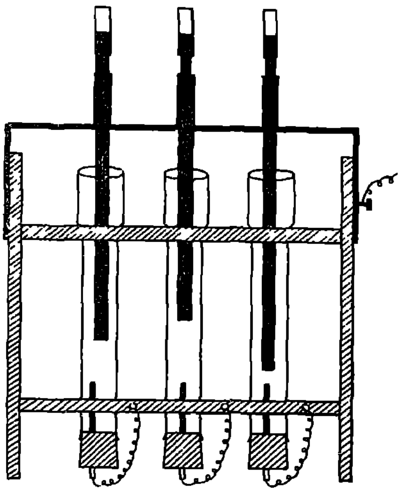


FIG. 65.

at the back of the room, but they are very clear to those in front. The colour at the centre, which should be white, is generally not easily discernible as such, at least in the hands of the writer. Often the heat melts the gelatine, but this does not prevent it re-solidifying later and being perfectly usable. In any case, the slides are easily made up afresh.

65. A "DIMMER" FOR USE IN THE FOREGOING EXPERIMENT

E. G. Savage

It is very useful to connect up each lamp in experiment 64 with a "dimmer." This[1] consists of three

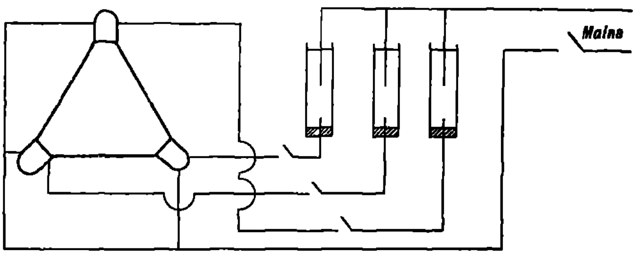


FIG. 66.

lamp chimneys, closed at the bottom by corks, through which project three pieces of copper or brass rod. From

[1] Contrived for the writer by Mr. E. H. Duckworth.

the top, fastened to a bar of iron, project three other pieces of similar, but thicker, rod, so that they slide stiffly in brass tubing, and with their ends protected by insulating rubber pressure tubing. The chimneys are filled with sodium sulphate solution, and by sliding the upper rods up and down, the resistance of each circuit, and therefore the brightness of each lamp, may be varied at will. Fig. 66 shows the diagram of the circuit; the three separate switches to the lamps are, of course, carried at the bases of the latter as parts of the holder.

66. COLOUR MIXING—COLOURED SHADOWS

E. G. Savage

Three apertures, or windows, each about 2 × 2 in., are cut in the bottom of an ordinary boot box. Over the middle one is placed a piece of blue filter (No. 20, S. E. Co.), and over the others a red (No. 14) and a green (No. 24) filter respectively. Behind each window, inside the box, is placed a small light. The writer finds that the small lamps in wooden cases with reflectors, sold by Messrs. Woolworth, serve admirably, but the effect is discernible even with short pieces of candle.

A sheet of white cardboard, to act as a screen, is set up, 1 ft. or 18 in. from the box (the lid of which has been put on or a curtain adjusted to cut off reflected light from behind), and some object (a solid wooden cone, about 6 in. high, is very convenient) is placed between windows and screen. The arrangement is shown in Fig. 67 (*a*). It is well first to cover up the red and the green windows. The screen is then illuminated with blue light, and displays a black shadow cast by the blue. If now the red window be uncovered, the general illumination of the screen becomes magenta, and two shadows are seen; that cast by the red is blue in colour, being illuminated by the blue light only; that cast by the blue is red for a similar reason. When the light from the green window is allowed to fall on the screen in addition, the general illumination

is quite definitely white, and the shadows become more complex and interesting. If the distance be so arranged that the appearance is that given in Fig. 67 (*b*), the shadow cast by the green is magenta (red plus blue);

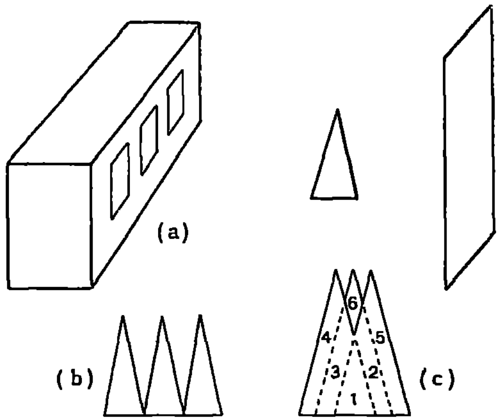


FIG. 67.

that cast by the red is peacock blue (green plus blue), and that cast by the blue is yellow (red plus green). If the distance be so adjusted that the shadows overlap, as shown in Fig. 67 (*c*), the colours are (1) black, (2) red, (3) green, (4) peacock blue, (5) magenta, (6) yellow, on a white ground, as each part of the screen is illuminated by none, one, two, or three lights respectively.

67. COLOUR MIXING—COLOURED SHADOWS IN DIFFUSED DAYLIGHT

E. G. Savage

If experiment 66 be carried out in diffused daylight, or in a room where there is only one not very bright, or rather distant, lamp, an interesting optical illusion is produced. In this situation, the screen is feebly illuminated only. When one blue lamp alone is switched on, the shadow is not black, but yellow, the complementary colour to the light switched on; similarly, with the red

11. ARCHIMEDES' PRINCIPLE

K. H. Cochran

Graduate a glass jar to measure ounces of water (a Nicolson hydrometer jar does very well). This is done to a sufficient degree of accuracy by pouring in 453·6 c.c., marking the surface A (1 lb.), then adding a second pound, and so obtaining B. Rub the surface of the jar from A to B with a carborundum hone, which will give a matt surface on which graduations may be marked in pencil. Divide AB into 16 equal parts.

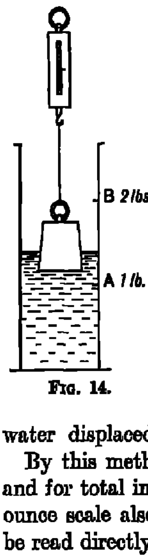


FIG. 14.

Use a spring balance reading 4 lb. × 1 oz. or ½ oz. ("Sportsman's" Tubular Balance). Suspend a kilogram weight and read the balance to nearest ounce. Read the water level, which should be adjusted exactly to a mark on the scale. Now partly immerse the weight and read balance and ounce scale again. The difference between the readings of the balance gives the upward thrust, and the difference between the scale readings is the weight of water displaced.

By this method the truth of the principle for partial and for total immersion may be shown. The graduated ounce scale also enables the *weight* of displaced fluid to be read directly.

The same jar may be used to demonstrate the truth of the principle for other liquids if two or more ounce scales are added, e.g. one for alcohol and the other for turpentine. The first jar may also be used to find relative densities of floating bodies. The body, when floating, displaces its own weight of water. Total immersion gives the weight of an equal volume of water.

chromatic yellow of the spectrum, (*b*) the mixture of red and green. Two questions arise therefore: (*a*) Will blue mixed with monochromatic yellow give a white as well as blue mixed with the compound (R + G) yellow? (*b*) If so, is the white light produced the same in the two cases? These questions can be answered experimentally. Using method (61) above, the spectrum gate may be employed to make the two different mixtures. If this apparatus is not available, method (63), with the three projectors, or method (68) may be employed. With either method, (63) or (68), colour filters must be used. To mix blue with compound yellow by method (63), a blue filter (48 Wratten or 20 S. E. Co.) is put in one projector and a compound yellow (12 Wratten or 1 S. E. Co.) is put in another. To mix blue with a monochromatic yellow, No. 73 Wratten must be used with either of the blues. If method (68) is employed, the appropriate pairs of slides must be made up. The result produced is in each case a white which cannot be distinguished by eye. They are, however, different in that the white produced by mixing the compound yellow with blue has, as one of its ingredients, red; the other white, in which monochromatic yellow is an ingredient, has no red in its composition. Accordingly, they may be distinguished. If a good saturated[1] red be placed in the white patches, in the first it will appear red. In the second it should appear black. In practice, it is not black because the filters are not sufficiently "pure," but it is a very dark brown indeed and differs unmistakably from its "natural" colour in ordinary white light.

70. COLOUR MIXING BY SUBTRACTION

E. G. Savage

Two lantern slides are made up as follows. A mask is cut from black paper of the shape shown in Fig. 68 (*a*),

[1] The red colour on a Swan Vesta match-box is a very good example of a saturated red.

the circles from which the figure is formed being about 1 in. in diameter. Three filters are then cut, such as shown in (*c*), and fastened in position over the mask so that the circular parts overlap, as shown in (*b*). When the three primary colours are used, the sectors 1, 2, 3 and 4 are black, while 5, 6 and 7 are red, green and blue. In practice, since the filters may let through a little red light, it may be found that 2, 3 and 4 are not quite black, but very dark brown, when held up to strong sunlight. They appear quite satisfactorily black with most lantern lights.

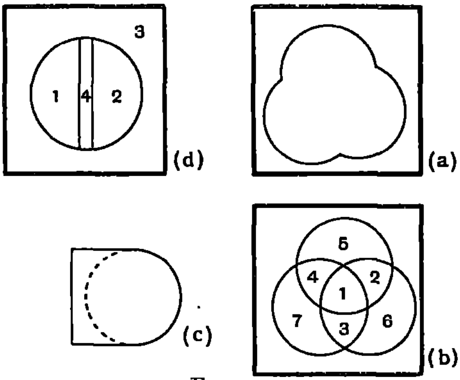


FIG. 68.

The second slide should be made in the same way, but, instead of using the three primary filters, the three "secondary" or double colour filters, magenta, peacock blue and yellow (S. E. Co. 12, 15 and 1), are employed. Then, while the sector 1 appears black, 2, 3 and 4 will appear red, green and blue respectively, while 5, 6 and 7 are magenta, yellow and peacock blue. That this process of subtraction is what occurs when pigments are mixed may be shown by drawing three large circles, say 6–8 in. in diameter, on cardboard and actually painting the three circles with the three colours. The overlapping sectors will then be found to display the same colours as does the slide. The cardboard experiment may be usefully compared with the record previously suggested for the mixing of lights. The difference between the

two methods of mixing may be finally clinched by showing that whereas a mixture of all the spectral colours produces white light, a mixture of all the corresponding pigments from a paintbox produces a black paint. The reason why a blue pigment, mixed with a yellow, produces green may also be made very apparent by superposing two filters on one slide. Since it is the one colour fact generally known, it is worth while showing how it comes about.

71. PSYCHOLOGICAL COLOUR MIXING

E. G. Savage

On a flexi-slide[1] (a thin transparent slide on which it is possible to draw with great ease and comfort), ruled in squares, colour each alternate square with different colours, e.g. red and green. When shown on the screen, each small square stands out distinctly in its own colour. Now throw the image out of focus. This corresponds to the production of circles of confusion on the retina produced by the dots of the colour printer. The patch appears yellow. More crudely, if such a square be drawn on a piece of cardboard with red and green crayons, it will appear yellow to the most distant member of the class, although those in front may still distinguish each separate dot or line of red or green. The result is clearer if on the same cardboard a separate red and a green square be drawn for comparison.

72. DEPENDENCE OF COLOUR UPON THE NATURE OF THE INCIDENT LIGHT

E. G. Savage

On a large sheet of cardboard is drawn any object, partly in black crayon and partly in red. For example, a face of a young man, bald, with closed eyes, is drawn in black. His opened eyes, a thick mop of hair, moustache and beard are drawn in red. This is hung up, covered

[1] Flexi-slides at about 1*s*. 9*d*. a dozen may be obtained from Relf Bros., Holborn.

with black paper and the lantern light is thrown on to it through a red filter. It is interesting to note how little light is reflected from the black paper. When this is removed, the class sees the young bald man. When the red filter is replaced by a green one, the face changes as by magic, and displays in black all those additions which fancy may have suggested to be drawn in red. The class is then not only ready but eager for the explanation. A variant of this is for the class to view the drawing in open daylight (*a*) through red filters, (*b*) through green filters, (*c*) with no filters. It should be possible similarly to make a drawing in green or blue which should "disappear" in a corresponding light, but, while it is extremely easy to find red pigments which are invisible seen through a red filter, the writer has not yet found satisfactory matches for other colours. He would be glad to hear of them.

73. ILLUMINATION BY MONOCHROMATIC LIGHT

E. G. Savage

A collection of eight or ten gaily-coloured posters, pasted on cardboard, is desirable. The sodium flame is best produced by using sodium chloride pencils (5*s.* 6*d.* a dozen), sold by British Drug Houses. These are hygroscopic, but are easily kept in a stoppered bottle. In any case, they recover their consistency after ten minutes' baking. Three or four Bunsens, each with a pencil in the flame, secured there by a stiff wire wound round burner and pencil, produce the most striking results.

DIFFRACTION

74. A SILK HANDKERCHIEF AS A DIFFRACTION GRATING

F. A. Meier

A small piece of silk handkerchief, stretched on a frame, is held in front of the eye. When a wide slit illuminated with monochromatic light is looked at, a series of images

parallel to one another and equally spaced will be seen. These will be most distinct when half of the threads of the handkerchief are parallel to the sides of the slit. Owing to the cross-threads in the handkerchief, the images will be elongated and the general appearance of parallel bands is produced.

When the handkerchief is moved towards the slit, the images will get closer to one another, and a position may be chosen so that the images just touch. These images are, of course, the first, second, third, etc., order spectra.

A convenient frame on which to stretch the handkerchief is that generally used for marking handkerchiefs. A hole, $\frac{1}{4}$ in. in diameter, is large enough for the eye to look through. Care must be taken to stretch the handkerchief uniformly in all directions.

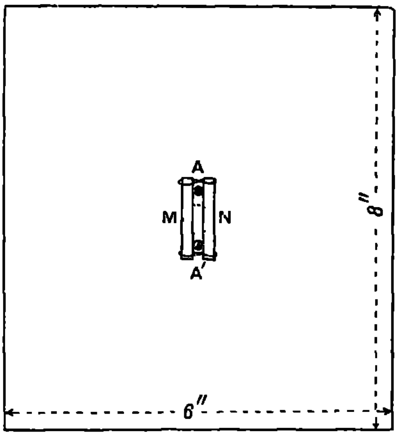


FIG. 69.

It is not necessary to have a travelling microscope to measure the spacing of the threads, though this is undoubtedly the most accurate method. Good results can be obtained by placing a scale on the handkerchief and using an eye lens of sufficient power to enable the number of threads to the cm. to be counted.

A slit with accurately parallel sides is a necessity, and not only so, but it must be of known width. Such a slit, if not available, can be constructed at the cost of 1*d.*, as described below.

Construction of Accurate Slit.—A hole, of about $\frac{1}{4}$ in. diameter, is drilled in a piece of wood (6 $\times$ 6 in. is con-

venient), as shown by the dotted circle. Four short pieces are then cut from the same fairly stout knitting pin. Two of these are fixed in the wood at A and A′, whilst the other two are held at M and N by two small rubber bands. In this way only a section of the hole is used as a slit, whose width is obviously equal to the diameter of the knitting pin, and which can be accurately measured by a micrometer screw-gauge. A skilful observer will be able to secure results within 1 per cent. for λ. An absolutely dark room is not essential, but direct light should be excluded.

75. WAVE-LENGTH, USING PIN-HOLE OF KNOWN DIAMETER[1]

F. A. Meier

The apparatus (Fig. 70) consists essentially of two cardboard tubes, each about a foot long, sliding one within the other. A small piece of ground glass, G, is forced through a saw-cut in the tube. The ends of the tube, T, are fitted with two corks, having holes $\frac{1}{2}$ in. or more in diameter. By means of short rubber bands, the two small pieces of aluminium foil in which pin-holes have been pricked can be kept in position at A and B. The pinhole at A is illuminated by a strong light of the gas-filled type, care being taken to exclude direct light from the eye. The spots of light are viewed with an eye-lens at L.

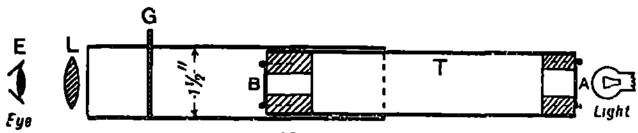


FIG. 70.

The success of the experiment depends on making accurate circular pin-holes at B. This is best done with a large needle. A small piece of aluminium foil ($\frac{3}{4} \times \frac{3}{4}$ in.) is placed on the flat end of a cork, and by a rotatory motion the needle is forced through it. Instead of one hole, it is more convenient to use about five holes in

[1] For Theory, see S.S.R. (V), 20, p. 287.

ascending order of diameter. The same needle will do for all the holes if a small piece of card is fixed on the needle and pushed along its length 1 mm. at a time. The holes will then be in ascending order of magnitude, and less adjustment will be required to obtain a black spot on the ground-glass screen for, at any rate, one of the holes.

It is surprising how accurate these holes can be made. I have repeatedly examined such holes afterwards with a microscope and found errors less than 1 per cent., which in a hole of 1 mm. diameter means an accuracy of $\frac{1}{100}$ mm.

By far the quickest way of measuring the diameter of the hole is to use a micrometer screw-gauge. A needle is chosen which does not quite go through the hole. The diameter of the part where it just sticks in the hole is then measured. In making this measurement, two hands are hardly sufficient to hold the needle, the screw-gauge, and to turn the micrometer head at the same time. It is therefore advisable to clamp the screw-gauge to the table while making the measurement.

Fig. 71 gives some sort of idea of what may be seen on the ground-glass screen, though the *sharpness of outline shown*

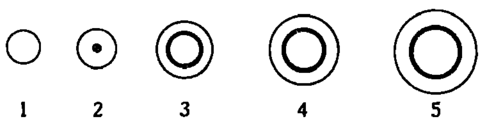


FIG. 71.

in the drawing must not be expected and cannot be obtained.

If the distance between screen and pin-hole at A is decreased, the black spot, instead of being No. 2, will move to No. 3, or even No. 4. A dark room is essential, since the amount of light entering A is very small. The diameter of the pin-hole at A should be about $\frac{1}{5}$ mm., while the diameters of the other holes should range from about ·3 mm. to rather less than 1 mm.

White light must be used for the experiment, since the usual monochromatic sodium burner does not give out enough light; but the wave-length found will be that

corresponding to the brightest part of the spectrum, namely, the sodium line.

It may be of interest to show an actual set of measurements taken with the apparatus :

$u = 21{\cdot}5$ cm. Diameter of hole $= {\cdot}0755$ mm.
$v = 29$ cm.

$$\lambda = \frac{r^2}{2}\left(\frac{1}{u} + \frac{1}{v}\right)$$

when the hole covers two half-period zones.

$$\text{Therefore } \lambda = \frac{{\cdot}0755^2}{8}\left(\frac{1}{21{\cdot}5} + \frac{1}{29}\right)$$
$$= 5{\cdot}8 \times 10^{-5} \text{ cm.}$$

76. DIFFRACTION RINGS OF A LENS

F. A. Meier

The following experiment shows that an ordinary convex lens does not give a geometrical point image of a small distant source of light, but a central bright disc surrounded by bright and dark rings. A rough value of the wave-length of light can be obtained by this method.

First, it is necessary to have a very bright point source of light. By using the filament of the 4-volt gas-filled bulb in experiment 53, but with the filament end-on, an almost perfect point source is obtained. At a distance of 5 or 6 metres from the filament, place a convex lens of 30 to 40 cm. focus. Catch the image on a piece of ground glass and focus a travelling microscope or micrometer eye-piece on to the minute image, then remove the glass. A bright spot without rings can be seen, for the rings are far too small to be visible. If, however, the aperture of the lens is decreased, the spot of light gets larger and rings begin to develop when the aperture is made small enough (say about 2 mm.). An iris dia-

FIG. 72.

phragm is more convenient to show the increasing diameter of the central spot and rings as the aperture diminishes, but a small hole drilled in a piece of metal plate is all that is necessary.

Care should be taken that the eye is not looking towards the windows, and the lens should be shaded so that direct light does not reach either face of the lens. As many as three or four rings can be easily seen. An achromatic lens gives rather better results, and the experiment can be carried out splendidly with a camera which has an iris diaphragm in front of the lens.

If two 4-volt bulbs are used, the overlapping of the images is seen when the bulbs are close together, and the overlapping may be such that the lens will not separate, i.e. "resolve" the two luminous points. When the aperture is increased, the rings diminish in size though the centres remain the same distance apart, and when the aperture reaches a diameter of about ½ cm., the two objects will be clearly resolved (Fig. 73).

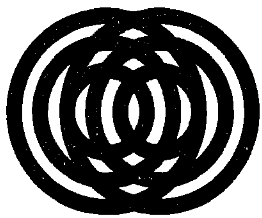


Fig. 73.

77. HALOES

E. G. Savage

For illustrating this phenomenon, there are still available a relatively small number of circularly ruled diffraction gratings at Messrs. Newton & Co., Optical Instrument Makers, 72 Wigmore Street, London, at 2*s.* 6*d.*, 5*s.* and £1 1*s.*, according to size. The number of rulings is of the order 6.000–7,000. To show the haloes, a lamp is placed in a light-tight box in which there is a small circular hole. This is focused on a screen by a convex lens. When the grating is interposed and adjusted, a beautiful halo will be seen around the hole.

DISPERSION (see also *Colour* and *Spectrum*)

78. RAINBOW

S. F. Dufton

The glorious phenomenon of the rainbow can be illustrated and the rainbow angle measured by using a colourless bottle or, best, a round-bottomed flask filled with water. A good beam of light is passed through the flask, which serves the same purpose as the raindrop of the rainbow, and as the eye is brought into the exact position of the bow, two colourless spots of light seen through the flask approach and, as they coalesce, burst into colour. The angles for the different colours can readily be measured ; also with care those of the supplementary bows.

With a beam from a lantern and a good-sized flask the rainbow ray can be projected on the screen.

79. FOCAL ISOLATION OF VIOLET LIGHT

B. M. Neville

The experiment illustrates the Wood-Reubens method of utilising the chromatic aberration of a lens for the isolation of ultra-violet light.

White light from a miniature arc is concentrated on a

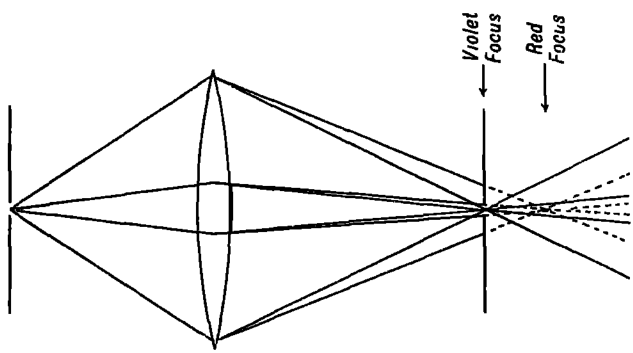


FIG. 74.

pin-hole and passes on through a convex lens, which converges each constituent to the conjugate focus corresponding to its own colour. By placing a second pin-hole where the light converges, and a stop to intercept that passing centrally through the lens, what finally gets through the system is white light minus all colours having wave-lengths greater than that corresponding to the position of the second pin-hole. The emergent beam becomes increasingly pure and brilliant as this pin-hole approaches the lens, and a certain amount of ultra-violet light may eventually be detected even when glass lenses are used.

ECLIPSE OF THE SUN

80. A DEVICE FOR ILLUSTRATING THE APPEARANCE OF THE CORONA

C. G. Vernon

The "sun" (S, Fig. 75) consists of an opal electric bulb, in front of which is placed a blackened sheet of cardboard, with a circular hole, 2 in. in diameter, opposite the centre of the lamp. The lamp-holder is so arranged that it can be moved backwards and forwards. The "moon," M, is a wooden ball, diameter 1 in., mounted on a stout pin. The terrestrial observer is a sheet of cardboard in which

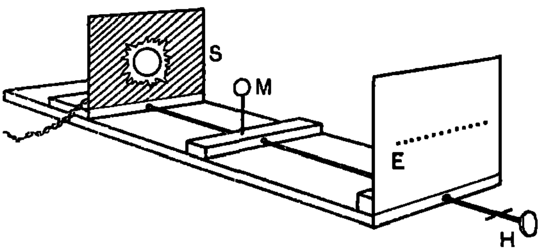


FIG. 75.

a horizontal row of large pin-holes, E, about ¼ in. apart, has been made. On the front of the black screen, a

"corona" is drawn in red chalk. (H is a handle for altering the position of the "sun.")

On passing the eye along the row of pin-holes, a wonderfully realistic series of stages of the eclipse can be seen; just at totality the corona becomes visible, nothing of it being seen otherwise, owing to glare. On the front of the "observer" screen the moon's shadow is visible; and if the "sun" is brought nearer until the umbra disappears, an annular eclipse is shown.

FLUORESCENCE

81. FLUORESCENCE IN ULTRA-VIOLET LIGHT

Oxford, 1921

Enclose a quartz mercury-vapour lamp in a box with an opening covered by a sheet of Wood's glass; with this arrangement, about 80 per cent. of the light which emerges is of wave-length 3,660 A.U., and none of the harmful rays (especially the line at 2,536 A.) are present.

With this illumination, the appearance of the audience is striking; teeth (real) show up brilliantly, even at the back of the room, while artificial teeth appear dull black, as do silver coins held up in the hand. Hair appears green, but this is only visible near the source, and eyes present a curious appearance. It is necessary to find a subject whose hair has not been oiled or greased for some time.

The following materials can be used to show fluorescence in ultra-violet light: fluorescein, uranium glass, a solution of chlorophyll in alcohol, zinc sulphide, calcium sulphide, paraffin oil, erithrosine, eosin, carbazol, a solution of quinine sulphate.

Note 1.—If a quartz mercury-vapour lamp is not obtainable, an arc may be struck between tungsten rods inserted in place of the carbon rods in a small Westminster arc lamp with suitable resistance. The objection to this is the copious formation of tungsten oxide if the arc is kept

going for any length of time. The same effect can also be obtained by a flaming carbon arc, though this is not quite so good.

Note 2.—Suitable "ultra-violet" glass can be obtained, together with interesting data concerning the same, from Messrs. Chance Bros., Birmingham.

INTERFERENCE

82. YOUNG'S FRINGES

B. M. Neville

A cardboard tube, about 1 ft. long and $1\frac{1}{2}$ in. in diameter, has one end closed by a piece of ordinary plane mirror, A, silvered side inwards. A cap with a small central hole closes the other end, about 2 in. from which

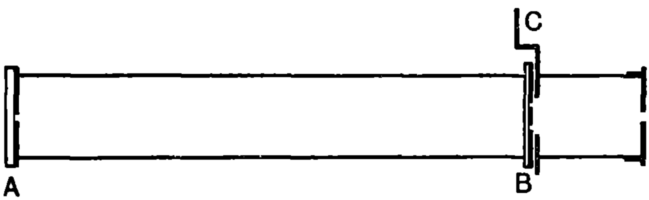


FIG. 76.

another strip of mirror, B, silvered side towards the cap, passes through two slots cut in the sides of the tube and is thus supported parallel to the first. Before mounting, a fine slit is ruled by means of a sharp-pointed penknife in the silver on the first glass, and two parallel slits in the second, the distance between the latter being about $\frac{1}{2}$ mm. A movable strip of zinc, C, passing through the same slots as the second strip of mirror, and pierced by a rectangular opening, is arranged so that one or both of the two parallel slits may be uncovered at will, a uniform patch of light or the fringes being seen accordingly through the spy-hole, when the tube is directed towards a light.

83. INTERFERENCE EXPERIMENTS IN DAYLIGHT

F. A. Meier

The greatest drawbacks to experiments on "Interference" in a school laboratory are generally held to be the necessity for a dark room and the intrinsic difficulties of the experiments themselves. The two following, both of which can be carried out quantitatively as well as qualitatively, can be done in daylight and without the skill or experience needed in using "Fresnel's Mirrors," or in setting up and measuring "Newton's Rings."

The possibility of doing the experiments in daylight depends on the fact that the filament of a 4-volt gas-filled type of bulb is used directly as the "line" source of light without the necessity of having to cut off a great deal of light by the interposition of a slit. Such bulbs are generally obtainable from Halford's Cycle Shops. The bulbs are gas-filled.

The filament is in the form of fine spiral of very thin wire, the spiral having a diameter of only about $\frac{1}{5}$ mm.

YOUNG'S FRINGES

Rule two parallel lines about $\frac{1}{3}$ mm. apart on a 3 × 1-in. piece of photographic plate, exposed and developed. Old fogged plates will do. The glass plate should be carefully clamped to the table. A good steel straight-edge is required. The lines are best ruled with the point of a steel needle; the finer the needle, the finer the lines will be. With a knife blade or razor blade it is not easy to rule lines of equal thickness, and this is essential for Young's Fringes if the best effect is to be obtained. The parallelism of the lines can be judged by eye, if the window is faced whilst the lines are being ruled. The fineness of the slits is remarkable. When a fine needle is used, they are less than $\frac{1}{30}$ mm. wide. Should the first set of lines be

unsuccessful, others may be ruled on the same piece of glass.

Arrange the slits vertically about 50 cm. from the filament set parallel to them by eye, so that the observer does not look towards a window, and with the film side of the plate away from the filament. Set up a travelling microscope or micrometer eye-piece 15–20 cm. from the slits, pointing in line with the slit and bulb. Without any further adjustment, a beautiful set of bands will be seen, two or three of which are black, whilst the others are coloured. These are Young's Bands, which he first observed by using sunlight through a fine slit with two other parallel slits. By slightly rotating the bulb whilst observing the bands, they may be improved. It is important to prevent any reflected light from the plate reaching the microscope.

If a monochromatic filter be used, the number of bands is considerably increased ; the best Wratten filters for this purpose are Yellow No. 73 and Green No. 74 in the Wratten Light Filter Catalogue. The cost is about 1*s*. 6*d*. for a 2-in. square. If mounted between lantern-slide covers, the cost is slightly more. Pieces 1 in. square are quite large enough for interference experiments.

Note.—Since it is very difficult to get the two slits truly parallel, their distance apart should be measured at the point through which the light passes into the microscope. This is found by slowly raising a piece of card in front of the slits whilst observing the fringes. As soon as they disappear, put a scratch on the plate at the point reached by the edge of the card.

PHOTOMETRY

84. BUNSEN PHOTOMETER FOR USE IN AN UNSHADED LABORATORY

S. R. Humby

It is often inconvenient to make elementary measurements of candle-power in a darkened room. For class

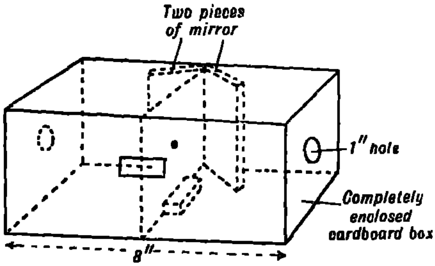


FIG. 77.

purposes, a photometer enclosed in a cardboard box will give good results in any room. Two pieces of mirror enable both sides of the $\frac{1}{2}$-in. grease spot to be viewed through a $1\frac{1}{2}$-in. hole cut in the front of the box, which is coated inside with dull black paint.

85. LUMMER-BRODHUN PHOTOMETER HEAD

John W. T. Walsh

This instrument, in its proper form, is a somewhat expensive piece of apparatus, but it is quite a simple matter to construct a rough Lummer-Brodhun Head from a cigar-box, a few pieces of mirror and a simple eye-piece. The method of construction will be seen from Fig. 78. S is a sheet of some white diffusing material; thin card covered with good white blotting-paper will do. M, M′ are two pieces of ordinary mirror, and L is a piece of front-silvered mirror, the silvering of which has

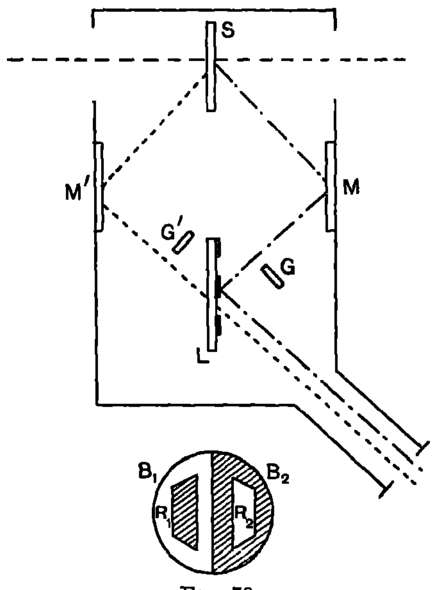


FIG. 78.

been carefully removed over the pattern shown clear in the diagram at the bottom of the figure. If, now, the two sides of S are illuminated by light from two lamps placed one on each side of the photometer head, the silvered part of L, i.e. the part shown shaded in the diagram, will reflect the right-hand surface of S, while through the unsilvered part of L the left-hand side of S may be seen. The point of balance may be found, therefore, by adjusting the position of the head until both the silvered and unsilvered parts of L appear equally bright. In fact, if the silvering is skilfully removed, the lines of demarcation between the silvered and unsilvered parts will almost disappear at the point of balance. The precision of a setting of this kind, however, is limited by the ability of the human eye to detect small differences of brightness. The minimum difference which the eye is capable of perceiving is about 1·7 per cent., so that when a photometric balance is being made, the photometer head is moved backwards and forwards fairly rapidly so that the field goes out of balance first in one direction and then in the other. The range between these two extremes is about $3\frac{1}{2}$ per cent., and the process of making a setting is to estimate the midway point within this range.

It has been found that the precision of the setting can be much improved if, instead of requiring the eye to judge when two parts of the field are equal in brightness, the judgment required is one of equality of contrast. Referring again to the diagram at the bottom of the figure, if the brightness of the trapezoidal patch, R_1, can be made a given percentage less than that of the outer field, B_2, while the brightness of R_2 is the same percentage less than that of B_1, it will be clear that at the balance-point the contrast between R_1 and B_1 will be the same as the contrast between R_2 and B_2. If, however, the balance be disturbed, the contrast will be increased on one side and diminished on the other. This effect is readily produced in the Lummer-Brodhun Head by inserting narrow strips of plain glass at G and G′. The

reflection losses at the surfaces of these strips cause a difference of about 9 per cent. between the brightness of each patch and that of the background of the other half of the field. Thus, at the position of balance, each patch is about 9 per cent. darker than its background, and it is found that the equality of contrast between patch and background on the two sides of the field is a very sensitive criterion of the position of balance.

The chief difference between the simple form of Lummer-Brodhun Head illustrated in Fig. 78 and the actual instrument as ordinarily used lies in the substitution of a double prism of glass for L, the reflection at the silvered surface being replaced by total reflection. A description of the head will be found in any good textbook.

For accurate work, not only is it necessary to use a suitable form of photometer head, but a bench and carriage allowing rapid and easy movement through the balance-point must be used. The screening of the head from all light except that coming from the lamps to be measured is also most important. When electric lamps are being measured, it must be remembered that a change of 1 per cent. in voltage causes a change of 3·7 per cent. in candle-power.

86. NEON LAMP PHOTOMETER

E. Bolton King

Apparatus required :

1 Photo-electric cell.
1 Neon lamp (Philips—not Osram).
1 Valve (PM5x).
2 Valve-holders.
2 Condensers (·01 and ·001 mfd.).
1 Loud speaker.
About 240 volts H.T.
6-volt accumulator for valve, 5 Ω grid leak, grid-bias battery, 50,000 ω wire-wound resistance.
Lamp to run on mains.

Circuit :

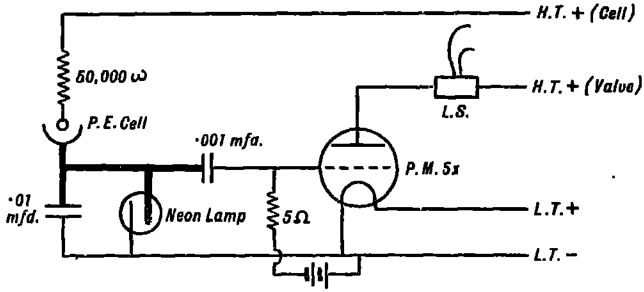


FIG. 79.

Fix up the circuit as shown, being very careful of the insulation of the part shown by thick lines. The cell voltage may be somewhat greater than the maximum given with the cell, but it should not arc.

On bringing a lamp towards the cell window, clicks will be heard on the loud speaker, which will increase in frequency when the light is brought nearer.

Adjust cell voltage and grid bias for maximum noise when the lamp is close to the cell.

REFLECTION

87. FORMATION OF A CAUSTIC

F. A. Meier

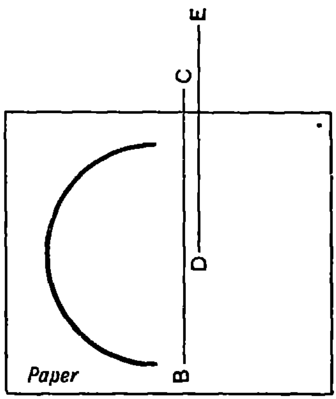


FIG. 80.

Take a piece of cylindrical mirror strip. Put a gas-filled lamp with vertical filament about 20 in. from the mirror and 4 in. above the table and a comb at BC. Slowly move a card, ED, across the comb so as to cut out the light. The gradual building up of a caustic is beautifully shown. A darkish room is essential.

Note.—A 4-volt Midget Ediswan bulb which has a fine, straight, special filament, or an ordinary 60-watt horse-shoe filament bulb, used sideways, gives good results.

REFRACTION

88. REFRACTIVE INDICES OF GLASS AND WATER

S. F. Dufton

A tumbler with a thick glass base serves excellently for the determination of the refractive indices of glass and water (F. G. Dufton, *School World,* February 1914). The tumbler is placed upon a sheet of paper, and a straight line is ruled along the shadow cast by a source of light some distance away. This gives the direction of the tangential incident ray. The tangential emergent ray is found by moving the eye until the last glimmer of light is seen upon the edge of the glass. The angle of

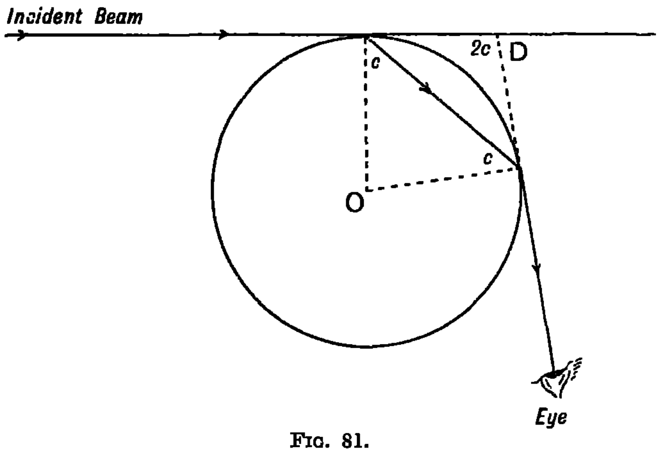


FIG. 81.

deviation of the tangential ray 2c is the supplement of twice the critical angle. The thick glass bottom gives the refractive index of glass, the upper portion that of any liquid desired. Any vessel circular in horizontal

section may be used, or even a hanging drop. An accuracy within 1 per cent. is easily obtained.

89. THE REFRACTIVE INDEX OF A LIQUID

G. N. Pingriff

The focal length of a thin converging lens (of, say, 20–30 cm.) is first found by placing the lens on a horizontal plane mirror and using the parallax method of fixing the position of coincidence of image and object. A second determination is then taken, after having placed a few drops of the liquid on the mirror before putting down the lens, and a third with the lens floating on clean mercury. The second measurement gives F, the focal length of the combined glass-water lens, and the third enables the radius of the lens face to be calculated by the well-known Boys method. The whole exercise gives admirable practice in the use of ordinary lens formulæ. The only apparatus required is a convenient holder for the pin, or sharpened wood splinter, which forms the object.

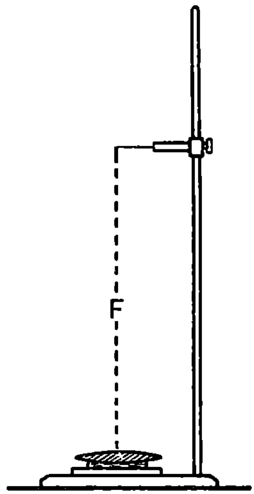


FIG. 82.

SCATTERING

90. BLUE SKY AND SUNSET EFFECTS (TYNDALL'S EXPERIMENT)

E. G. Savage

A trough with plate-glass sides is required ; one about 4 in. square and 2 ft. long is convenient. In the trough place a solution of sodium thiosulphate containing 1 gram

per 100 c.c. To 5 litres of the solution, which is about the volume that the above tank requires, add about 75 c.c. of hydrochloric acid, made up of 72 c.c. water and 3 c.c. hydrochloric acid S.G. 1·16. This strength produces the first faint beautiful blue cloud in about 2½ minutes and gives time for explanations to the audience. It takes 5 or 6 minutes to go to completion, and enables the audience to watch first the yellowing and then the reddening of the "sun" before the final obscuring takes place.

SPECTRUM (see also *Colour* and *Dispersion*)

91. BECKMAN BURNER FOR FLAME SPECTRA

Oxford, 1921

A solution of a salt of the element of which the spectrum is to be obtained is placed in a small wide-mouthed flask. Hydrochloric acid is added, and some pieces of magnesium are dropped in. Over the flask is held the burner, which consists of a glass T-piece, the upper end of the vertical limb being of silica; it would probably be convenient to have the whole T-piece of silica. The coal-gas jet is fixed in the side tube as shown in Fig. 83. A very good and steady flame is thus secured, and to obtain the spectra of a number of elements, it is only necessary to have flasks containing appropriate solutions and to place them successively under the burner. The dimensions of the burner appear to be important; in the one shown, the length of the vertical tube is 150 mm., and its diameter about 10 mm.; the jet opening is about 0·75 mm.

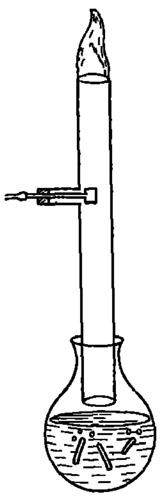


Fig. 83.

92. A STEADY FLAME FOR SPECTROSCOPIC AND INTERFERENCE WORK

C. E. L. Livesey

This apparatus (Fig. 84), devised by Rev. B. J. Whiteside, S.J., consists of a test-tube connected to the Bunsen by a short piece of tubing. The coal gas passes through a glass tube into the test-tube, and out to the Bunsen through a side tube, near the bottom. In doing so, it disturbs a layer of finely powdered dry salt, and carries it forward to the flame. An inch depth of salt will give a bright flame for several hours. The amount of salt can be regulated very simply, and if the passage to the burner becomes stopped up, the salt is readily shaken back by a gentle tap.

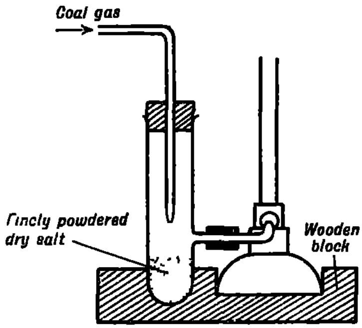


FIG. 84.

93. A DEMONSTRATION SPECTRUM

Rev. B. G. Swindells, S.J.

The following is an adaptation of the method shown by Dr. Hartridge at the Cambridge Meeting in 1923 (*S.S.R.*, (XV) Feb. 1923). The apparatus described happened to be at hand, but the same results should be obtained with any science lantern, and a grating and prism of equal dimensions.

The lantern, shown diagrammatically in Fig. 85, is a Stroud and Rendell Science Lantern (Reynolds & Branson, Ltd.). A slit, which in this case is adjustable, is mounted in a wooden diaphragm (D, Fig. 85) which can be placed

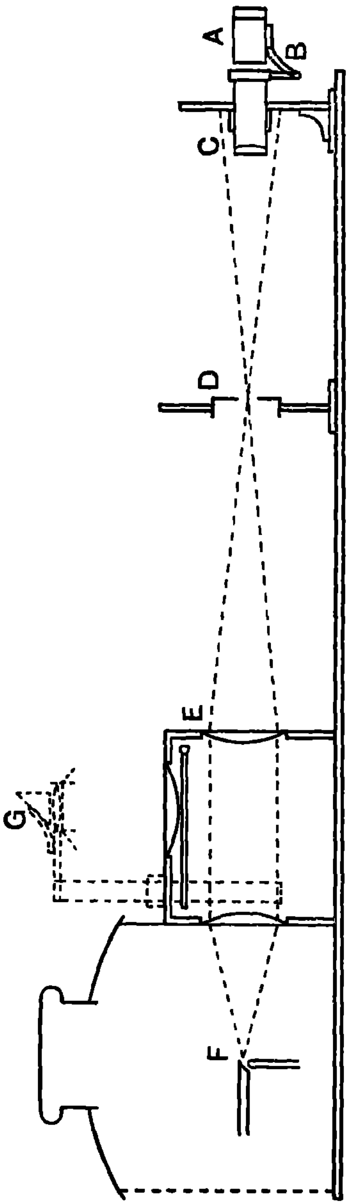


FIG. 85.

at different distances from the condensers, E. The light from an arc, F, or a "Focuslite" lamp (which is more often used), is brought to a focus on to the slit, and this in its turn is focused on the screen by the objective, C. In the figure, A represents the prism cell, which, however, is placed in position only after the slit has been focused on the screen.

The prism in the cell A is a right-angled isosceles prism, the hypotenuse face of which measures 3 × $2\frac{1}{2}$ in. The smaller faces thus measure $2\frac{1}{8}$ × $2\frac{1}{2}$ in. On the hypotenuse face, and covering it all except for a small margin all round, is a grating replica, which Messrs. Griffin & Tatlock mounted directly on the glass (A and B, Fig. 86). The rulings of the grating are parallel to the shorter edges of the hypotenuse face. This prism and grating have been mounted in a wooden cell (shown in plan in Fig. 86. and in front elevation in Fig. 87). The inside of the cell

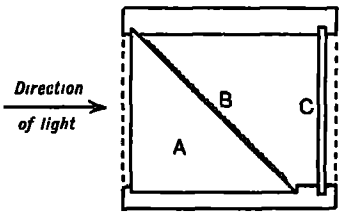


FIG. 86.

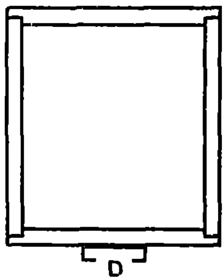


FIG. 87.

is, of course, blackened. A window of plane glass (C, Fig. 86) has been put in at the open end of the cell. This certainly entails a loss of light, but it protects the grating from dust and damage.

To hold the cell in front of the objective, use is made of the fitting (B, Fig. 85), which is provided with the lantern to hold the erecting prism (shown at G). A piece of bent metal (D, Fig. 87) slides on to this fitting, which has been slightly altered to accommodate the cell.

When the slit has been focused on the screen, as

described above, the cell containing the prism and grating is put in place with the smaller face of the prism next to the objective. A spectrum will then be formed on the screen. It will be slightly out of focus, but a small readjustment of the position of the objective suffices to bring it into focus.

With the apparatus described, using as a source of light a 5–10-amp. arc, with an objective of 8-in. equivalent focus and with the screen 36 ft. away from the lantern, a brilliant spectrum is obtained, 10 ft. long and 1 ft. broad, and visible all over a lecture hall of length about 70 ft. and breadth 40 ft. When thus used, the slit is placed at a distance of 9 or 10 in. from the condenser, and the objective is 7 in. from the slit. The spectrum thus obtained shows absorption phenomena exceedingly well.

For temporary experimental purposes, very good results are obtained if an ordinary transparent grating replica is placed with the glass back up against the hypotenuse face of a right-angled isosceles prism. Total reflection at the prism face is prevented by wetting the face with water or glycerine, so that a film of the liquid is formed between the two glass surfaces. The combined prism and grating may then be placed on a stand in front of the lantern objective after the slit has been focused as described, and a good spectrum will be obtained. It is clear that the bigger the prism and grating, within the limits of the objective, the brighter will be the spectrum produced.

94. A DEMONSTRATION SPECTRUM

E. H. Duckworth

The following method is based on a demonstration by Dr. Hartridge at the Cambridge Meeting in 1929. It gives a spectrum 6 ft. long and 8 in. wide.

An arc-lamp, with carbons at a right angle and their tips almost in line, is a convenient source of light to use, but I have found a 10-amp. Triumph "Focuslite" gas-filled

filament lamp very satisfactory, and on alternating current it is less troublesome than an arc. An arc on A.C. tends to rotate about the carbons and to get out of position.

The light is concentrated with a small condenser (A, Fig. 88) on to a slit, B, measuring 5 × 1 mm. A suitable condenser is about 5·5 cm. diameter and 6 cm. focal length. The slit can be made from razor blades,

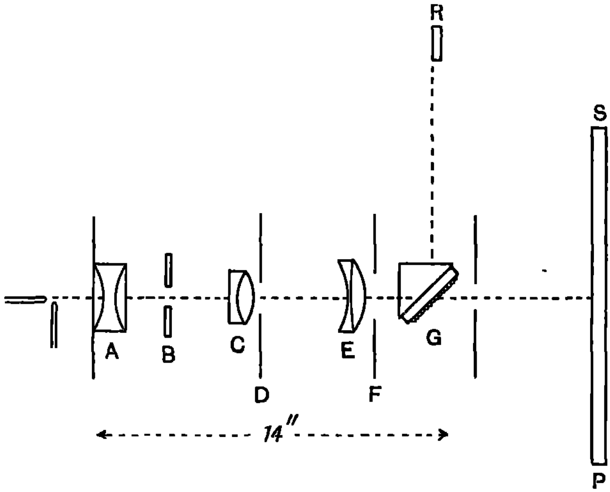


FIG. 88.

mounted in a metal frame. If an arc-lamp is used, it is a slight advantage to place a 6-dioptre cylinder lens between the condenser and the slit, to spread the light in a vertical direction over the slit. The lens, C, is achromatic, 3·8 cm. diameter, focal length – 5·5 in. D is a diaphragm to stop stray light, E another achromatic lens, 5·4 cm. diameter, focal length – 10 in., and F another diaphragm. G is a right-angled prism, the hypotenuse measuring 7·5 × 6 cm. On the hypotenuse is cemented, with Canada balsam dissolved in xylol, a diffraction grating. This is a Browning replica of a Rowland diffraction grating, 14,438 lines per inch and mounted on a rectangular block of glass. H is a screen with a rectangular hole in it to cut out stray light.

To adjust the apparatus, the prism with its grating is removed. The lamp is adjusted to illuminate the slit as brightly as possible, and the lenses, C and E, are moved up and down the optical bench to give a clear real image of the slit on the screen. The prism is then put in the position shown, and a splendid spectrum results at SP. An image of the slit by total reflection appears at R.

The absorption spectra of dyed gelatines, etc , can be beautifully demonstrated by placing them in the beam between the lamp and the prism. The colour by transmitted light shows at R. A card with red letters pasted on black paper and passed through the spectrum shows changes from red to black, and a method of rapid theatre scene changing can be demonstrated in a striking way by making drawings in coloured crayons and passing them through the spectrum. The spectrum is best projected on a strip of white paper, pasted on a sheet of black paper.

If it is desired to have the screen between the apparatus and the audience, engineers' tracing cloth makes a good transparent screen.

95. ARRANGEMENT FOR OBSERVING THE SPARK SPECTRA OF METALS

Oxford, 1921

When sparks are passed between poles of the given metal, the spectrum of the metal is to a great extent masked by the air spectrum obtained at the same time, but this difficulty can be overcome by altering the character of the discharge. The coil or transformer is connected to a condenser, which is connected through an inductance to the spark gap. The inductance is provided with a short-circuiting switch, and when this is closed, the air spectrum is very marked. On throwing the inductance into circuit, the air lines are suppressed, and the metallic spectrum shows clearly. The best value for the inductance must be determined by trial.

SOUND

96. THE PRODUCTION OF OSCILLATORY CURRENTS OF MUSICAL FREQUENCY

S. R. Humby

MANY interesting experiments with sound waves can be done with inexpensive apparatus by means of a three-electrode valve circuit. This is used to generate electrical oscillations which, when passed through a telephone receiver, cause its diaphragm to vibrate at high audible frequencies. Such a circuit, fitted with a variable condenser and suitable inductance coils, will give sounds of a very wide range of pitch.

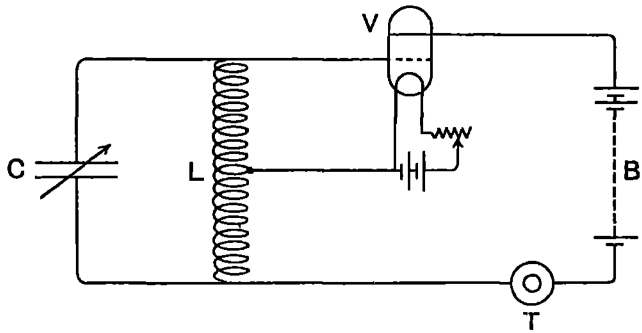


FIG. 89.

C = condenser, 0·01 microfarad maximum.
L = inductance 1,500 turns of 26-gauge insulated wire of mean diameter 3 in. The mid-point of the coil was connected to the filament of the valve.
V = any form of 3-electrode valve.
B = 60–200-volt battery or D.C. mains.
T = 2,000-ohm telephone receiver.

The circuit is set up as shown in Fig. 89.

It is convenient to mount the valve-holder, filament resistance and variable condenser on a board wired with six terminals for + and − low tension, + and − high tension, and + and − telephone. A triple flexible connection with coloured tags can then be used to connect different inductance coils, L, to the apparatus, because it is difficult to get one coil to give the wide frequency range desired.

The inductance used for sounds of frequency range 4,000 to 16,000 has 1,500 turns of 26-gauge insulated copper wire, wound by lathe without any special care.

A former is made by screwing two 6-inch diameter discs of three-ply wood to the opposite ends of a cylinder of wood, 2 in. in diameter and 2 in. long. On this the coil is wound without attempting to separate successive layers of the insulated wire ; the turns are recorded on a revolution counter and the filament connection is taken out at the 750th turn. The coil is mounted on a board with three suitably marked terminals.

It is not easy to obtain a variable condenser of maximum capacity 0·01 microfarad, since these are no longer used on wireless receiving sets. A few second-hand ones are still to be bought from instrument dealers.

A substitute can be made by combining a 0·001 variable condenser with a number of fixed condensers of the type used in wireless receiving sets.

A lower frequency coil can be improvised from the secondary winding of an old induction coil. One such coil gave a frequency range 500–1,200 with the 0·01 microfarad variable condenser. The circuit could be made to oscillate at frequencies down to 250 by connecting a fixed condenser of 0·05 microfarad capacity in parallel with the variable one.

A cheap loud-speaker unit, or a telephone ear-piece, is used as the source of sound.

For the best results use a magnetic unit which is fitted with an adjusting screw by which the distance

between the telephone magnets and the diaphragm can be altered when necessary.

97. AN ELECTRICALLY MAINTAINED TUNING FORK

S. R. Humby

A tuning fork can be kept in vibration by arranging the loud speaker or telephone-pole pieces (experiment 96) near one prong of the fork and adjusting the oscillator till its frequency coincides with the natural period of the fork.

This arrangement is very simple, and has some advantages over the more usual form of valve-controlled tuning forks which have, in recent years, begun to supersede those forks which are fitted with mechanical interrupters.

AUDIBILITY

98. SOUNDS OF VERY HIGH FREQUENCY ARE INAUDIBLE

S. R. Humby

One of the oscillators (experiment 96) has its coils so chosen that it can be used to observe the upper limit of audibility for the human ear ; as the condenser's capacity is reduced, the sound becomes inaudible rather suddenly. The limit of audibility is very different for different persons : some can hear the whistle quite distinctly when to other ears there is no sound.

DETECTORS

99. DETECTORS AVAILABLE IN SOUND EXPERIMENTS

S. R. Humby

In experiments in sound, the usual detectors available are the ear (assisted when necessary by a stethoscope

tube), the sensitive flame, the microphone and the Rayleigh disc.

The Sensitive Flame

As a detector for high-pitch sound waves, it is convenient to use the Tyndall "sensitive flame." Such a flame shows well-marked resonances, and often responds sharply to a very limited range of frequencies. It is important therefore that, in experiments with the sensitive flame, the oscillator is first adjusted until the flame shows a vigorous response to the sound. When this is done, it is possible to use gas at the pressure at which it is supplied, instead of being compelled to use it at much higher pressures.

Make a jet by drawing out 1 cm. glass tubing to about 1 mm., and adjust the gas pressure by a screw clip till the flame responds to a hiss. Then tune the oscillator till the flame gives a marked response.

It is best to try a number of jets, since their sensitiveness is very variable. Usually, a jet with a rather jagged edge responds better to high-pitch notes than does a smoothly cut jet. Jets cut off by scissors are usually better than those cut more carefully with a glass file.

The Carbon Microphone

A sensitive carbon microphone, connected in series with a dry cell and a quick-acting dead-beat galvanometer, suitably shunted, can be used as a detector in many experiments with sound waves.

100. A MANOMETRIC CAPSULE

E. Nightingale

This will be understood from the diagram. The collodion is a penny balloon, and is held tightly between the cardboard tubes. The rubber bung contains two glass tubes, one for the gas supply and the other attached

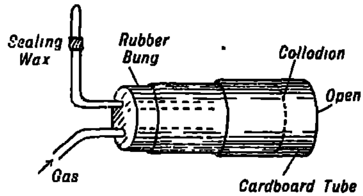


FIG. 90.

by sealing-wax to the jet. This may be made by pulling out a glass tube, but is better if made by pulling out a piece of silica glass tubing heated in an oxy-hydrogen or oxy-coal-gas flame. The silica jet does not soften when the gas is burning, whereas the glass jet does.

DIFFRACTION

101. DIFFRACTION EFFECTS WITH SOUND WAVES

S. R. Humby

Short sound waves can be shown to give diffraction effects closely resembling those obtained by optical diffraction. Thus, after passing through a rectangular aperture, the sound waves are found to give maxima and minima of intensity in positions which, when plotted on a diagram, are very like the photographs of the optical diffraction fringes at a narrow slit.

Two large drawing boards, clamped upright in the same plane, with an aperture about 4 in. wide, will show these effects well at a frequency of 10,000.

With a single board the diffraction effects near a straight edge can be examined, and the steady fall of intensity within the geometrical shadow can be compared with the maxima and minima just outside the edge of the shadow.

The telephone source should be set level with the middle of the edge of the board and about 3 ft. from it, and the fringes looked for 6 in. to 1 ft. behind the plane of the drawing board.

Diffraction effects with short sound waves are so well defined that the attention of the observer may often be

drawn to optical effects which may have been overlooked until the corresponding effect in sound leads him to look again at the optical analogue. For example, in Arago's experiment to obtain the bright spot at the centre of the shadow of a circular object cast by a point source, besides the diffraction rings outside the geometrical shadow, there are well-defined rings concentric with the bright spot inside the shadow. They can most easily be seen by using as object a very small ball-bearing and having a small round pin-hole in front of an electric lamp. The corresponding effect in sound is at once noticed if a source and sensitive flame are set up about a yard apart, and a disc of thin wood, about 4 in. in diameter, is slowly slid between them, taking care that the centre of the disc is kept level with both source and detector.

102. AN ACOUSTIC ZONE PLATE

S. F. Humby

A zone plate for sound waves can be made by marking on cardboard or thin metal a set of concentric circles whose radii are proportional to the square roots of 1, 2, 3, 4 and 5. The cardboard is then cut through along the circumference of each circle, so as to free the central disc and the four concentric rings. A suitable size for sound waves of length 3 cm. is obtained by making the radius of the inner ring 7·7 cm. This gives a theoretical focal length (for 3 cm. waves) of

$$-\frac{(7\cdot 7)^2}{3} = -20 \text{ cm.}$$

In order to hang up the zone plate, it is convenient to fix a thin wooden rod across the apparatus just above the centre. Two thin nails can then be driven through each zone so as to fix it to the rod, and the nail holes can then be punched out just large enough to allow the zone to be hung on the rod when desired.

Set up the zone plate in a vertical plane and put the

source 30 cm. from it on its axis. Remove the first (central), third and fifth zones, and adjust the position of the flame until it shows a maximum disturbance with the tip of the jet on a line with the source and the centre of the zone plate.

An actual adjustment, with $u = 30$ cm., gave maximum effect with $v = 57$ cm. beyond the zone plate.

$$\text{Hence } \frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-57} - \frac{1}{30}$$

$$\text{and } f = -\ 19{\cdot}7 \text{ cm.}$$

It is found that, with care, the changes of intensity can be shown as each zone is inserted or removed. Thus, the central zone alone removed gives a violent disturbance, which almost disappears when the next zone is taken out, and zones 2 and 3 will also neutralise each other's effects, whereas 1 and 3 reinforce.

Further details of these experiments and of the apparatus are given in the *School Science Review*, No. 36, of June 1928, and No. 44, of June 1930, also in the *Proceedings of the Physical Society*, August 15th, 1927.

DOPPLER EFFECT

103. THE DOPPLER EFFECT

S. R. Humby

Two sources giving slow beats (see No. 106) show the Doppler effect when one of them approaches or recedes from the other. Adjust the frequency of one oscillator until the beats are occurring at a rate of three or four per second. Notice the exact frequency of the beats. Now move one of the sources steadily, either towards or away from the other, and it is at once evident that the rate of the beats changes, showing that, relative to the flame, the frequency of one of the waves has altered. The ear also detects the alteration in the speed of the beats.

It is, of course, possible to calculate the velocity of

approach from the observed change of frequency, just as astronomers estimate the relative motion of stars by the displacement of lines in their spectra.

INTERFERENCE

104. INTERFERENCE EFFECTS WITH SOUND WAVES FROM A SINGLE SOURCE BY TWO PATHS

S. R. Humby

The usual lecture experiment to show interference of the sounds which pass by two different paths from a source to a detector can be performed with apparatus which can be constructed in a few minutes. Fig. 91 shows details of the arrangement. When the sliding tube, B, is moved in or out, the sensitive flame, F, shows alternate maxima and minima of disturbance, and the wave-length of the

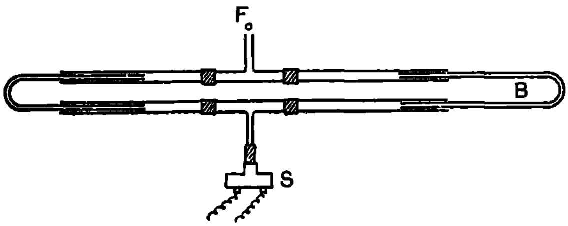


FIG. 91.

sound can be measured by reference to a scale placed beside the apparatus. Two 20-in. lengths of glass tubing, bent to form U-tubes, slide easily in 9-in. glass tubes, which are joined by rubber tubing to brass T-pieces.

105. INTERFERENCE EFFECTS WITH SOUND WAVES FROM TWO SOURCES

S. R. Humby

Two separate oscillators, or two telephone sources, connected to the same circuit, give a most striking illustration of the interference of sound waves. They can be placed

near a flame which is very sensitive to their sound, but the flame will be undisturbed in certain positions, although, when one source is silenced, the flame roars violently under the influence of the other.

Two telephone sources, connected in the same circuit and placed 2–3 ft. apart, give a complete hyperboloid fringe system. The distribution of the fringes in this case is similar to that of the optical interference pattern obtained in the Fresnel double-mirror experiment or Young's two-slit experiment.

When it is desired to do this experiment with two independent oscillators, they should be placed near enough to each other to interact slightly when they are brought into unison, or it may be difficult to maintain the two frequencies constant.

106. BEATS BETWEEN TWO SOUNDS

S. R. Humby

Two telephone oscillators, driven by separate circuits, give very marked and easily controlled beats. The sources can be adjusted to any desired frequency, and so can be used to illustrate the physical causes of consonance and discord. The change from slow to rapid beats can be clearly heard, then discord and, finally, two separate notes with an easily recognised " Combination tone," of which the frequency is evidently the difference between those of the generators. This difference tone can be heard even when both oscillations are of inaudible pitch—as is painfully obvious to every owner of a wireless set when howling is produced through the oscillation of a neighbour's receiver.

When beats are allowed to affect a sensitive flame, it becomes clear that the beats are interference effects which are moving at relatively slow speed across the room. Thus two sensitive flames may with care be adjusted near each other so that their movements are out of step and one rises as the other falls. Hence, observers

at different places hear the maximum disturbance at different instants.

107. AN ACOUSTIC ANALOGY TO THE "FADING" OF WIRELESS SIGNALS

S. R. Humby

When the reflecting surface is moved (see No. 110) the stationary wave system is also moved, so that at any particular point maxima and minima of disturbance occur. This reproduces the conditions under which the "fading" of wireless signals occurs owing to interference effects due to reflection of the electrical waves at the Heaviside layer.

In a similar way, when the frequency of the sound is slowly and continuously altered, interference fringes sweep across the space near the reflector so that a sensitive flame shows alternate maxima and minima. Observations of the number of such disturbances for a known range of wave-length change enable us to calculate the path difference between direct and reflected rays. It was by this method, applied to wireless waves, that Professor Appleton calculated the height of the Heaviside reflecting surface from which the electrical waves are reflected back towards the earth (*School Science Review*, No. 39, March 1929).

REFLECTION

108. TO ILLUSTRATE THE LAWS OF REFLECTION OF SOUND

S. R. Humby

The laws of reflection of sound can be demonstrated by the use of high-pitch notes. Tyndall's experiment gives very good results with sounds of frequency 10,000 and a sensitive flame.

The experiment is best done by cutting two holes at the middle of a 2-ft. tube of metal, so that the sensitive

flame jet can be placed inside and the flame then lit. The telephone whistle is fitted in the end of a similar tube, and the two tubes are set at any convenient angle. A plane mirror is now moved until the flame shows the greatest response. It is evident that both of the laws of reflection are "obeyed," and if you place your eye behind the flame, you will see in the mirror the image of the telephone at the far end of its tube (Fig. 92).

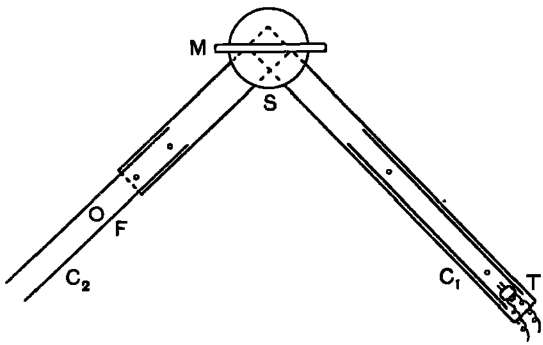


FIG. 92.

C_1 and C_2 = tubes, 2 ft. long × 3 in. diameter, screwed to wooden strips as shown.
T = telephone whistle.
F = sensitive flame.
M = mirror.
S = wooden disc with 360° scale.

By placing the source at the focus of a large concave mirror, a beam of high-pitch sound can be directed across the room so as to be audible at particular places or to affect a distant flame. It is convenient to weaken the sound very considerably by means of a shunt of adjustable resistance connected across the telephone coils, or by reducing the plate voltage. A large clock glass, or a cylindrical mirror, made by bending a sheet of three-ply wood, makes a very efficient substitute for the more expensive metal mirrors.

The reflection of beams of sound by concave mirrors can even be shown with the mirrors used in optical experiments, and it is then seen that the correct adjustment for maximum disturbance of a sensitive flame gives also the image of the bottom of the flame focused on the source of sound.

109. A MODEL WHISPERING GALLERY

S. R. Humby

Three-ply wood or stout cardboard can be used to make a model whispering gallery round which the high-pitch sound waves will creep.

The sensitive flame acts well as detector, and a rectangular strip, as small as 30 × 5 in., will show all the effects (see Bragg, *World of Sound*, p. 84).

110. STATIONARY SOUND WAVES FORMED IN FRONT OF REFLECTING SURFACES

S. R. Humby

When waves of sound are reflected from any surface, the result of the interference between the incident and the reflected waves is a series of stationary waves, so that at particular points in the air changes of density only occur with no motion of the air particles. At such points, the nodes, the ordinary form of sensitive flame will burn undisturbed, although these are places at which the ear hears a maximum of sound. The positions of the nodes and loops in front of a large plane surface give a simple method of measuring the wave-length of the sound. The measurement can be made by moving the flame, mounted for convenience on a little trolley fitted with rubber tyres, or the mirror can be moved parallel to itself.

On the line drawn through the source at right angles to the reflector, the points of least disturbance are half a wave-length apart, so that there the wave-length can easily be measured.

A series of actual measurements of positions of least disturbance were 2·1, 4·1, 6·3, 8·3, 10·9 cm., which are in the ratio 1, 2, 3, 4, 5, and which give the wave-length as 4·2 cm. The stationary waves formed by a loud high-pitch source in a room can be heard when the head is moved near any of the walls. Many people have probably noticed the effect when a broadcasting station is broadcasting its tuning note. It will be remembered that stationary light waves set up by reflection in front of a plane mirror were used by Lippmann in a rather difficult method of colour photography.

When the stationary wave pattern is examined at points where the incidence of the sound waves is oblique, we obtain effects analogous to Lloyd's single-mirror interference fringes in optics.

Since any particular fringe is associated with a particular path difference between the incident and the reflected waves, the fringes lie on hyperboloid surfaces.

Careful measurements over a large horizontal plane in front of a vertical mirror show that the stationary waves are disposed along hyperbolæ; and the path difference from the source and from the virtual image to any point on a particular hyperbola is found to be remarkably constant.

RESONANCE

111. EXPERIMENTS TO ILLUSTRATE RESONANCE

S. R. Humby

The apparatus (experiment 96, Fig. 89) gives very useful illustrations of resonance. One cannot help noticing the increased response of the telephone diaphragm to certain frequencies. If the alternating current is led into a wireless loud speaker, it is instructive to note the variations in loudness of the sound emitted.

If we now connect a loud-speaker horn to the vibrator,

we get some idea of the effect of the horn at different frequencies. Those who know that amusing watch-dog, "Radio Rex," may like to test the frequencies to which he responds. One specimen lies quiet except for two fairly sharply defined notes, either of which make him leap from his kennel.

Sharply tuned responses of a steel wire of a monochord can be produced by removing the telephone diaphragm and adjusting the pole pieces near the middle of the wire. When the alternations of the current are brought into tune with one of the natural periods of the wire, the latter is set into violent vibration and the vibration can be maintained indefinitely.

TRANSMISSION

112. SOUND WILL NOT PASS ACROSS EMPTY SPACE

S. R. Humby

The telephone receiver as a source of sound is more convenient than the electric bell usually employed to show that sound will not travel through a vacuum. The telephone can be hung by a piece of elastic within a small bell-jar and fitted with very thin coiled wires, to connect it to the oscillating circuit (see experiment 96). The loudness of the note is easily regulated, and when the air has been pumped out of the jar, there is no sound. The note can be very loud when air is allowed again to enter the jar.

VIBRATION IN PIPES

113. KUNDT'S TUBE

S. R. Humby

Another striking example of resonance, that of a long air column to a loud note, can be shown by connecting a

horn loud-speaker unit by a short length of wide rubber tubing to a long glass tube. This gives the Kundt's tube apparatus for measuring the velocity of sound in any gas. Dry lycopodium powder or cork dust is placed along the tube, and the oscillator (experiment 96) is made to give a loud note of moderately high pitch. The length of the air column is varied by means of a piston until the powder is violently disturbed. It then settles into heaps at half wave-length intervals, from which the velocity of sound can be obtained if the frequency has been determined. The frequency is easily found, either by adjustment with a fork of known pitch, or by measuring the wave-length of the stationary waves in air for which the velocity is accurately known.

114. KUNDT'S EXPERIMENT AND THE END CORRECTION

Eric J. Irons

As a source of sound, a brass tube, about 1 cm. in external diameter and 1 m. in length, is suitable. A cork cone, of height about 2 cm. and base slightly less than the cross-section of the glass sound tube, is required. It should be pierced along its axis with a hole (under 2 cm. in length), into which the brass rod fits firmly, the base of the cone being directed away from the rod. Additional security, which is essential for good results, may be obtained by the use of sealing-wax. When fixing the cork in this manner, it will be found better to heat the rod rather than the wax. The other end of the rod may be weighted (by means of a screw protruding into, and soldered to, the rod) until it balances about its centre. The rod is clamped at its centre between two triangular prisms of wood by means of four bolts and nuts, in the manner shown in the diagram.

As an indicator of nodes and loops, cork dust, obtained by sifting filings through a fine mesh, is preferable to lycopodium, since with cork dust the need for much pre-

caution to ensure dryness is unnecessary. The dust is first laid in a narrow band along a metre scale. By inserting the scale into the tube, tilting and tapping it sharply, the dust is deposited in a line along the bottom of the tube. The formation of the figures is facilitated by rotating the tube through an angle of some 60°.

The apparatus being set up and the sound tube furnished with a closely fitting movable stop, it should be found possible to obtain figures for almost any position of the stop. When the stop is adjusted so that its distance from the end of the rod is approximately an integral

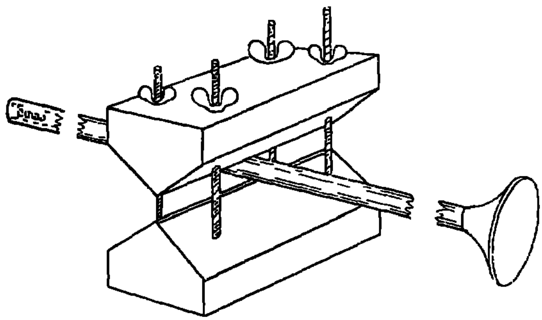


FIG. 93.

number of half wave-lengths, good figures, showing well-defined striæ, should be formed with one, or at most two, strokes of the rod with a resined duster. It will be seen that thick and thin striæ alternate in the loops. Continuous stroking causes the dust at the antinodes to shift along the tube and form into heaps at the nodes ; these heaps enable the half wave-lengths to be determined with precision.

For a photographic record of dust figures formed by the use of this apparatus the reader is referred to the *Philosophical Magazine*, Vol. VII, p. 523 (1929).

Removing the stop altogether, it should be found possible to obtain good figures with an open tube ; moving the tube relatively to the end of the rod may give rise to better results. If care be taken that the end of the sound

tube protrudes over the bench carrying the apparatus and is removed from any obstacle likely to give rise to a reflected wave, a convenient means for estimating the end correction of the tube is afforded. For, the value of the half wave-length ($\lambda/2$) of the disturbance in the tube being known from the nodal or antinodal distances, and the distance (c) of the antinode nearest the end from that end being measurable, it follows that the end correction (usually expressed in terms of the radius of the tube) is ($\lambda/2 - c$).

Experiments made in this way for notes corresponding to half wave-lengths of 6·6, 7·7, 10·7 and 19·7 cm. yielded values of the end correction respectively equal to 0·57, ·62, ·58 and ·64 times the internal radius of the tube.

For teaching purposes this method has an advantage over that of Blaikley, in that it gives an ocular demonstration of the fact that an antinode is not strictly at the end of an open tube. Further, from a knowledge of the half wave length of the disturbance in the tube, and the frequency of the exciting note (obtained by means of a sonometer), the velocity of sound in air is immediately calculable. The alternative of determining the velocity of sound in the material of the rod, given that in air, is also possible.[1]

As an alternative source of sound, a telephone diaphragm actuated by a valve oscillator and amplifier may be used to form the dust figures.

115. THE FREQUENCY OF A RESONATOR

Eric J. Irons

The frequency of a resonator is given by $n = a/2\pi\sqrt{c/V}$, where a is the velocity of sound in the gas contained in the reservoir of volume V, and c is the conductance of the orifice of the resonator.[1]

To test the dependence of n on V, a large dropping funnel or similar vessel (diameter about 15 cm.), having

[1] Rayleigh, *Theory of Sound*, Vol. II, p. 174 (1926).

a small opening, is suitable. The practice of the method is to introduce water into the funnel until it resounds to a tuning fork; the adjustment to unison is facilitated by listening for beats between the fork and the note emitted by blowing across the mouth of the reservoir. The volume of the reservoir having been measured (by determining the difference between the volume of water to fill the reservoir to the *bottom* of the orifice and the volume of water it actually contains), and the experiment repeated with a number of tuning forks of known frequencies, a curve may be drawn between V and n, or, for senior classes, a logarithmic plot of these quantities made to demonstrate the constancy of the product of frequency into the square root of the volume. An example of such a plot, using a resonator of volume 1,870 c.c. and forks whose frequencies varied between 128 and 512 cycles per second, is shown in the figure.

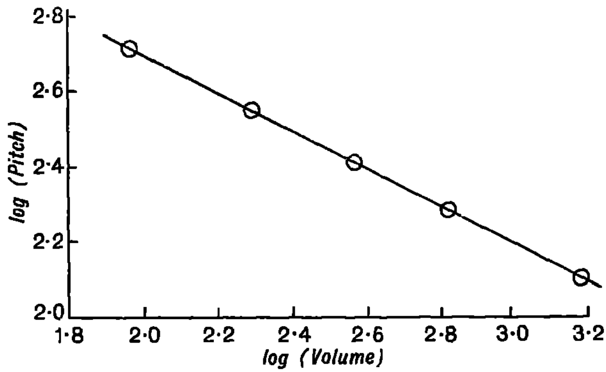


FIG. 94.

Assume pitch $\times$ (volume)^k = constant.
Then log (pitch) = $- k$ log (volume) + log c.
Gradient of line = $-$ ·51.
$\therefore k = \frac{1}{2}$ (approx.).
$\therefore$ pitch $\times \sqrt{\text{(volume)}}$ = constant.

The dependence of n on c (with V constant) may be examined by experiments in which the notes obtained

from an ocarina are determined by a sonometer. (The conductance of a circular hole in a thin wall is approximately equal to its diameter, and the resultant value of c due to a number of open holes is found by adding the constituent values, as in the electrical case of conductances (in parallel [1]).)

VIBRATION OF RODS

116. THE FREQUENCY OF VIBRATION OF A TUNING FORK

S. R. Humby

A 12-in. diameter wooden disc is fixed on the revolving table of a gramophone. Round the edge of the disc is fastened a strip of paper blackened in a flame of benzol. The paper strips are easily and very cheaply made by sawing through a roll of paperhangers' "lining paper." A $\frac{1}{2}$-in. bristle is fixed by a small piece of soft wax to the end of one prong of the fork, and this is touched, while vibrating, against the revolving paper. The speed of revolution is found by the use of a stop watch.

The wave trace on the paper can be "fixed" by passing it through a dilute solution of shellac in alcohol. Three consecutive experiments with the same fork gave frequencies 384, 385 and 384. The change of frequency, due to the soft wax and the bristle, was found (by counting beats) to be about $\frac{1}{4}$ per second.

117. THE RELATIVE FREQUENCIES OF THE FUNDAMENTAL AND FIRST OVERTONE OF A ROD CLAMPED AT ITS CENTRE

Eric J. Irons

When a rod about 2 m. in length is clamped at its centre, it is possible to elicit the fundamental and first

[1] Rayleigh, *loc. cit.* and p. 178.

overtone separately and distinctly. The vibration of the rod in the two instances is represented in the conventional manner in the figure, from which it may be observed that the frequency of the overtone is three times that of the

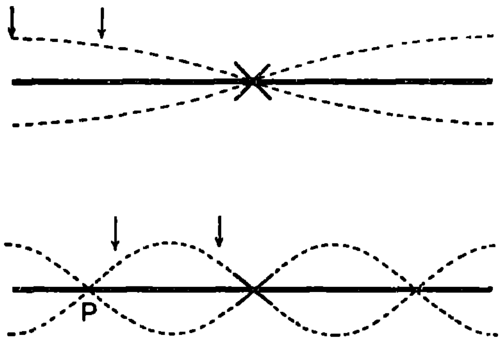


FIG. 95.

fundamental. To obtain the notes, the rod should be stroked with a resined duster between the points indicated by the arrows ; when sounding the overtone, any trace of the fundamental may be eliminated by holding the rod between two fingers at P. If the rod be used to drive a Kundt's tube in the manner described in experiment 114, the half wave-length of the fundamental in the air of the tube may be seen to be three times that of the overtone, indicating that the frequencies of these two notes are as one to three.

VIBRATION OF STRINGS

118. A SCREW-ADJUSTABLE SPRING BALANCE FOR SONOMETER WORK

D. G. A. Dyson

It is difficult to obtain very satisfactory results with a horizontal sonometer and the usual pulley and weights when these results depend on a knowledge of the tension

of the wire. This is due to friction at the pulley. Much better results are obtained by the substitution of a screw-adjustable spring balance, reading to 20 kilograms.

A $\frac{1}{2}$-in. square iron rod, rather more than twice as long as the full extension of the balance, is forged round for half its length and tapped with a $\frac{7}{16}$-in. thread by a local ironmonger. This passes through a $\frac{1}{4}$-in. thick iron plate, bolted to the end of the sonometer, and through a metal strip bent into a square arch, which serves as a guide and also prevents twisting of the rod when screwed up. The balance hooks on to a small screw at the end, and the tension is easily adjusted to any value by means of the wing-nut.

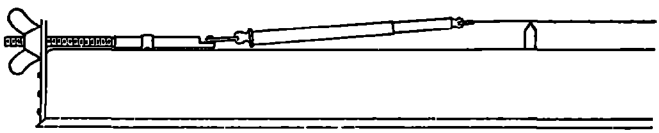


FIG. 96.

Corrosion of the ordinary piano steel is often troublesome ; the substitution of spring-tempered Firth " Staybrite " steel wire has been found most satisfactory. This is rustless and, at the same time, has an exactly known density of 7·93 grams/c.c., so that the mass per unit length can be obtained from its diameter, and the necessity for cutting and weighing is obviated. It has a tensile strength of about 100 tons per square inch, which is only slightly inferior to piano steel ; a good size for all-round work is No. 24 S.W.G. (about ·56 mm.).

119. MELDE'S EXPERIMENT

E. Nightingale

A suitable fork is made by bending a piece of steel, about 32 in. long, in a vice. When clamped to the

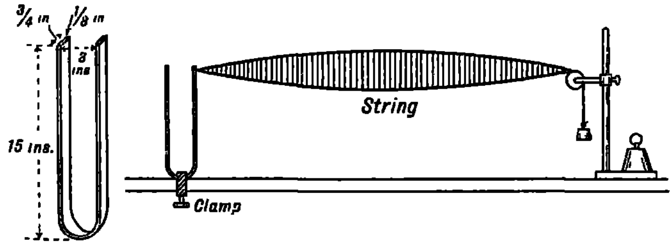


Fig. 97.

bench, this will vibrate a long time when plucked between thumb and forefinger. Some results obtained are as follows:

Mass of String 1·7 Grams per Metre

Load.	Length of String.	No. of Loops.	Ratios of	
			Length of Loop.	Tension.
400 grams	2·5 metres	1	4	16
100 ,,	2·5 ,,	2	2	4
25 ,,	2·5 ,,	4	1	1

120. ALTERNATING CURRENT USED TO PRODUCE A RESONANT VIBRATION IN A STRETCHED WIRE

W. E. Pearce

The interesting feature of this experiment is the volume of sound it produces. Stretch a thick iron wire (No. 16 S.W.G.) over a sonometer by a heavy weight (50 lb.). Around a piece of soft iron, I, 1 in. in diameter, wind 300

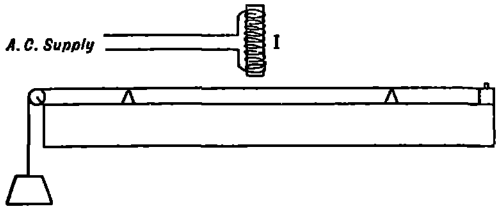


Fig. 98.

turns of wire and pass a current of 5 amps. from the A.C. mains through it. Then place it just over the centre of the iron wire. If the latter be adjusted so that its length is such that its period of vibration is the same as that of the periodicity of supply, the wire vibrates strongly. The enhanced effect of exact tuning illustrates clearly the tendency of the wire to vibrate with a definite period. The application of this to the ordinary commercial frequency meter is well worth while.

WAVE MACHINES

121. SPIRAL WAVE MACHINE

F. G. Luton

Wrap a double layer of corrugated cardboard round a cardboard tube of 2 or 2½ in. diameter. Round this "former" wind about 80 turns of No. 18 S.W.G. bare copper wire in a close coil. Secure each end by twisting it on to the adjacent turn. The presence of the corrugated card makes the removal of the coil from the "former" a simple matter. Carefully stretch the coil to form an open helix with about ½-in. spacing between the turns. Load each turn with a small piece of lead. The combination of low elasticity with considerable mass gives a low velocity, and the waves are easily seen.

122. TO PROJECT THE WAVE FORM OF A GRAMOPHONE RECORD WHILE THE INSTRUMENT IS PLAYING

S. R. Humby

The relation of amplitude, frequency of vibration and wave form to loudness, pitch and quality are strikingly illustrated by this apparatus. The apparatus is inexpensive, and if the demonstration is to a small class, a flash lamp, with a "point" filament, gives sufficient light. (For a large lecture-room use a motor headlamp or an arc light.)

Attachment of Mirror.

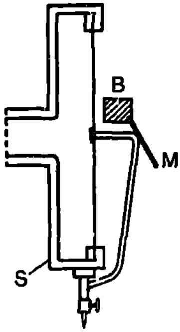


FIG. 99.

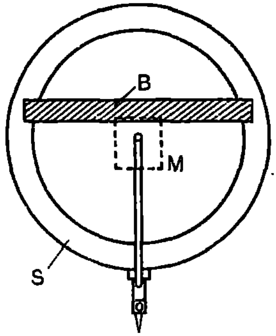


FIG. 100.

S = old type of gramophone sound box.
B = a bar of brass fixed to the metal edges of the sound box.
M = a microscope cover slide, silvered to act as a light plane mirror. It is stuck, with rubber solution, to the bend of the rod which vibrates the sound-box diaphragm and to the small groove on the brass bar. (It hinges at this latter place.)

Optical Arrangement (not to scale).

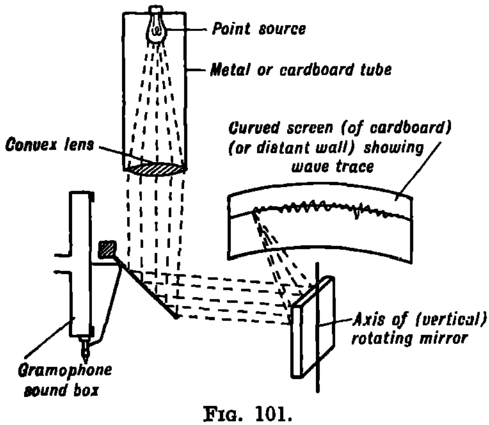


FIG. 101.

123. COMBINED MAGNETISER AND DEMAGNETISER FOR USE ON ALTERNATING-CURRENT LIGHT MAINS

F. A. Meier

It is possible to use a solenoid with *alternating* current, not only for *de*magnetising bar magnets, but also for *re*magnetising them. The apparatus needs but little description. It consists of a solenoid, 40–50 cm. long, having about 6 layers of No. 22 insulated copper wire for 110-volt supply, wound on a metal tube. Square wooden or fibre ends serve to keep the wire in place. A tapping key and fuse are put in the circuit and a plug adaptor to fit the electric light, as shown in Fig. 102.

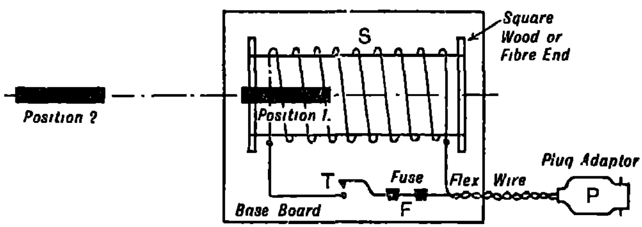


FIG. 102.

The resistance of the solenoid should be so high that a maximum current of 4–5 amps. is not exceeded. A continuous current of 5 amps. would, of course, heat the solenoid too much, but not if the current is used only intermittently, as would actually be the case. For a 220-volt supply, a resistance in series with the solenoid will be required. The whole apparatus is mounted on a base-board which can be fixed near the electric-light

switch, so that it is always ready for use in the laboratory.

(I) *To "Demagnetise" a Bar Magnet.*—Place the magnet in the solenoid in position 1 (see Fig. 102) and, keeping the tapping key depressed, withdraw the magnet along the axis to position 2. Then do the same, inserting the other end of the magnet. It should be completely demagnetised.

(II) *To "Remagnetise" a Bar of Steel.*—Place the bar right inside the solenoid and *momentarily* depress the tapping key. The bar will be found to be magnetised.

The arrangement just described is a great convenience in the laboratory. It should be permanently set up so that any boy can magnetise or demagnetise a magnet or piece of steel that he is going to use, instead of having to rely on its being in a suitable magnetic condition. There is a fuse in series with the solenoid for safety. A small compass needle is let into the base-board on which the coil is mounted, so that the polarity of the magnets after magnetisation can be tested. It is a good thing for a boy to realise that it is quite possible for the end of a magnet marked N to be a south pole, and that the only safe way is to test it at the start.

124. SUSPENSIONS FOR OSCILLATING MAGNETS

F. A. Meier

A very convenient arrangement is that shown in the diagram. A piece of No. 18 Eureka wire, W, bent as shown, is soldered at the lower end into a small piece of brass rod with a hole and tiny set-screw to clamp the magnet. An ordinary wire connector sawn in half will serve the purpose. Another similar piece, or the other half of the wire connector, is soldered to the other end, and in it is clamped a sewing needle to act as the pivot. The centre of gravity should be vertically below the point of the needle. The needle rests on a piece of glass held in a wooden clamp. With such an arrangement, the

magnet will swing freely for a minute. No glass case is needed if the room is moderately free from draughts, but a cylindrical ring of paper or thin card, 3 or 4 in. wide, is advisable. The needle can, of course, be renewed at any moment without trouble.

The moment of inertia of the suspension is so small as to be negligible (i.e. less than 1 per cent.) as compared with that of a piece of a thick knitting needle, about 5 in. long, used as the oscillating magnet. Such a magnet

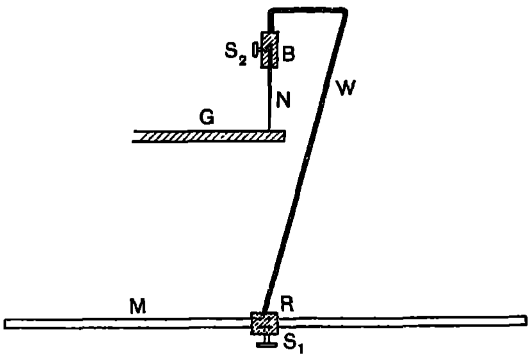


FIG. 103.

will give a deflection of 30 to 40 degrees on a magnetometer and good results for H, besides saving a considerable amount of annoyance. The knitting needle should be hardened by heating to a bright red heat and then plunging into cold water.

For suspending heavier magnets, artificial silk such as is used for embroidery will be found very satisfactory. The silk generally consists of three main strands, each of which is made up of about 40 fibres. If one end of one of the main strands is fixed, it is quite easy to untwist the fibres and take as many as are required to support the magnet. One fibre holds about 10 grams. If the ends are slightly moistened, the fibres cling together and can easily be tied. A convenient stirrup can be made out of a piece of gummed label. The restoring couple

due to such a composite thread is very tiny and negligible compared to the earth's restoring couple exerted on the magnet.

ELECTRO-MAGNETISM

125. AN ELECTROMAGNET TO WORK OFF A 3·5-VOLT DRY BATTERY AND LIFT 35 LB.

E. H. Duckworth

The original electromagnet constructed by Sturgeon was in the form of a horse-shoe. After all these years, apparatus dealers still sell miserable red horse-shoe contrivances at 8*s*. each, or more, for class demonstration, that bear not the slightest resemblance to the monster lifting magnets used in engineering works.

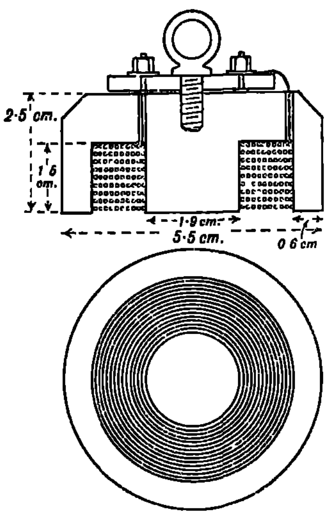


Fig. 104.

A magnet taking 0·5 ampère and capable of lifting an iron block 35 lb. or more in weight can be made as follows at a cost of 4*d*., if a lathe is available. The efficiency of the design depends on keeping the magnetic field closed and the reluctance small.

The dimensions are shown in the figure. A piece of wrought iron, 5·5 cm. diameter and 2·5 cm. thick, was not available for turning, but a blank of suitable size was hammered out on an anvil after heating in a small forge. To get the iron thoroughly soft, it was finally made red-hot, covered with glowing coke and left to cool. It was then turned up in a lathe and a channel was cut in the front face for the embedded winding.

The winding used consists of 1¾ oz. of No. 28 D.C.C. wire, held together with paraffin wax. The winding of the coil was done in a lathe on a wooden former (Fig. 105). Before the coil was slipped off, it was treated with hot paraffin wax. To prevent the wire sticking to the wooden former, the wood was, previous to winding, covered with thin paper.

The coil should be made a little smaller than the channel cut in the iron; it is then quite an easy matter to slip it into position flush with the face of the magnet. Holes are bored in the bottom of the channel and the ends of the coil are brought out to small terminals fixed on an insulating slip of wood.

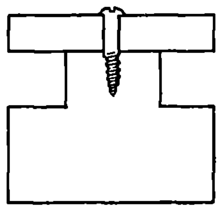


FIG. 105.

If the iron has been well softened, there will be very little residual magnetism and, used with a 4-volt accumulator, it is almost impossible to detach this magnet from a block of iron.

126. MAGNETIC STRENGTH AND THE MAGNETIC PROPERTIES OF DIFFERENT METALS

E. W. E. Kempson

In the following experiment, magnetic strength is measured by the pull of a magnet on its armature; the magnetic properties of different metals can be compared by their pulls under equal conditions. The magnetisation curve will have ampère-turns as abscissæ, which will therefore be proportional to "H"; ordinates will represent pull, and will therefore be proportional to "B^2" instead of "B," as in the ordinary magnetisation (B — H) curve.

Two electromagnets of equal dimensions are made, one of wrought iron, the other of cast tool steel. A good magneto steel is to be preferred to the tool steel if it can be obtained. Each electromagnet is made of round

rod, 1 in. in diameter, forged to a semicircle of 5 in. outside diameter; the armature of each magnet is an equal semicircular piece; the faces of contact between the magnet and its armature should be filed flat, scraped and rubbed down with carborundum powder, so as to make really good contact—this part of the work requires good but not particularly expert fitting. Fig. 106 shows the general arrangement of one of these magnets and its armature.

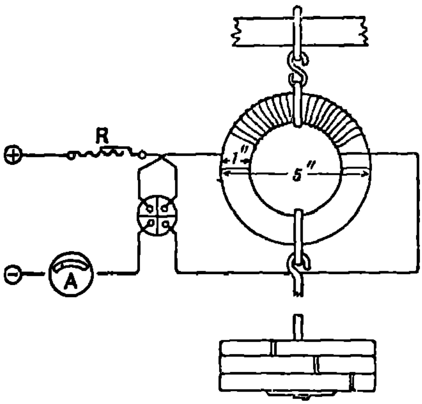


FIG. 106.

In the particular experiment described here, the electric circuit of the wrought-iron magnet had 73 turns, that of the cast-steel magnet 146 turns; current was available up to about 20 ampères, so that the maximum number of ampère-turns was about 1,500 for the wrought iron and 3,000 for the cast steel. A circular magnetic circuit was chosen as being simple and easy to make, but probably another shape would do as well; a shorter circuit would be more convenient in some laboratories, for it would require proportionally fewer ampère-turns.

The magnetising ampère-turns are increased step by step, and at each step the load on the armature is increased until this breaks the magnetic circuit and the armature falls off.

Tables of actual values for the wrought iron and cast steel are given, and the results are plotted in Figs. 107 and 108. For comparison, corresponding values of ampère-turns and total magnetic flux in "maxwells" were also observed, and have been plotted on the same figures with the same scales of abscissæ.

TABLE 1. WROUGHT-IRON MAGNET

Ampère-turns.	Pull.	Ampère-turns.	Flux.
	lb.		maxwells.
0	0	0	0
44	7	44	10,000
83	31	73	28,500
110	53	146	52,500
153	89	219	62,000
237	125	336	68,500
372	153	584	75,500
621	183	—	—

TABLE 2. CAST-STEEL MAGNET

Ampère-turns.	Pull.	Ampère-turns.	Flux.
	lb.		maxwells.
0	0	0	0
372	3	292	9,250
467	10	438	19,000
533	13	775	41,000
620	26	1,520	67,000
730	33	2,120	76,000
876	51	—	—
1,170	73	—	—
1,970	123	—	—
2,550	133	—	—
2,820	143	—	—

The curves of "pull" and "ampère-turns" exhibit the chief characteristics of the ordinary magnetisation curves; the convex and concave bends illustrate well the rapid increase in permeability in the initial stages, followed by a decrease in permeability as the condition approaches saturation; there is a marked difference in magnetic permeability in the two metals throughout.

It is interesting also to compare the actual pull of the magnet with that calculated from the equation: Pull $= \frac{B^2A}{8\pi}$ dynes. In measuring the flux recorded in Table 1, the exploring coil of the fluxmeter was wound over the middle of the magnetising circuit, and it is likely that

the flux at this part of the circuit exceeded in some degree that across the two surfaces of contact.

The complete "Hysteresis" curve may be plotted in the same way but this is a tedious business and seems

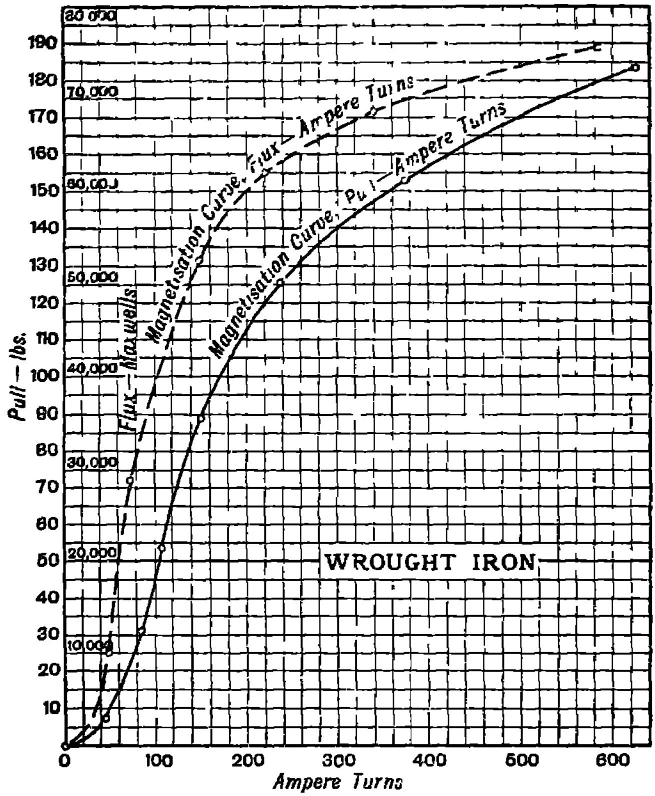


FIG. 107.

hardly worth while at this stage. It is, however, a simple matter to obtain two important points on the "Hysteresis" curve—those where the curve cuts the vertical and horizontal axes of co-ordinates—the former by measuring the pull required to break the magnetic

circuit when the electric current has just been reduced from its maximum value to zero, the latter by measuring the value of the reversed ampère-turns necessary to destroy the magnetism of the circuit so that the unloaded armature will just drop off. The values so obtained show

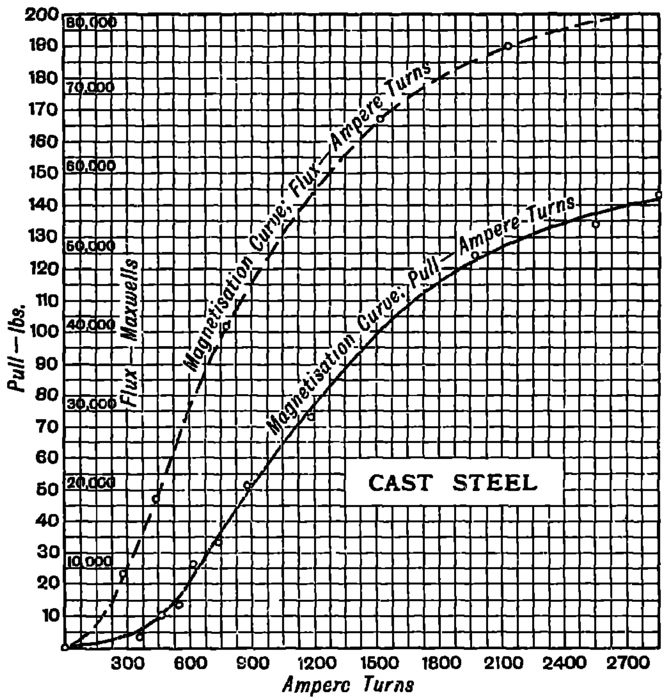


Fig. 108.

clearly the great remanent magnetism in the wrought iron, the low retentivity of this metal and the relatively high retentivity of cast steel under demagnetising force. A striking demonstration may be given to show that hammering a wrought-iron magnet is not alone sufficient to destroy magnetism, for the wrought-iron ring may

be struck with a hammer, or dropped on the floor, without breaking the magnetic circuit.

127. TO ILLUSTRATE THE TENDENCY OF MAGNETIC TUBES TO SHORTEN THEMSELVES

M. Finn

Take a short piece of glass tubing, about $\frac{1}{4}$ in. internal diameter, and heat the middle in a Bunsen flame, turning the tube round so that the wall becomes thicker and the bore of the tube becomes very small.

Slightly bend the tube at the heated part in the shape of the letter V.

When cold, pour dilute sulphuric acid into the tube, fix it in a stand and connect up to the lighting mains, through lamps in parallel, by means of thin wires dipping in the liquid. Pass current. The lamps light, but immediately go out. At the same time, the thread of liquid in the bend of the tube breaks, a spark passes and the current stops. The continuity of the liquid is then restored and the lamps glow once more. This action continues so long as the electrodes dip in the acid. The repeated sparking will, if allowed to go on, crack the tube at the bend. Any conducting liquid, such as mercury, as well as any electrolytic solution, could be used.

Each element of the circuit conveying an electric current is surrounded by magnetic tubes having the shape of closed curves, the circuit and each tube being interlinked like two links of a chain. Each tube tends to shorten itself and shrink back on to an element of the circuit. Each element of the circuit is thus being throttled by the magnetic tubes around it. It can be shown that an element of the conductor experiences an inward pressure proportional to i^2/d^2, where i is the strength of the current and d the diameter of the conductor. If at any point in a *liquid* conductor the cross-sectional area be reduced, the pressure over the element

will be greater than over neighbouring elements, and the liquid will tend to break where the cross-section is least. A form of current interrupter based on this principle is described in No. 144.

MAGNETIC MEASUREMENTS

128. THE INVERSE SQUARE LAW

J. E. Calthrop

In this experiment a square and a cylindrical cobalt-steel magnet of the same length are placed horizontally on a sheet of glass, used as an inclined plane so that the magnets repel each other.

The nearest distance from A (Fig. 109) at which the cylindrical magnet B comes to rest is found, and in this position it may be assumed that friction is acting down the plane, and against the magnetic repulsion.

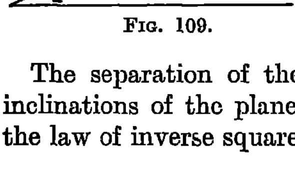


Fig. 109.

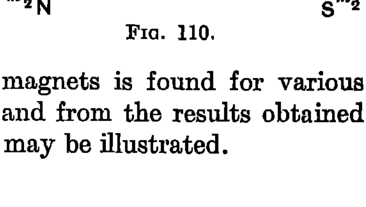


Fig. 110.

The separation of the magnets is found for various inclinations of the plane, and from the results obtained the law of inverse squares may be illustrated.

Theory

Let d be the separation of the magnets, m_1, m_2 the respective pole strengths, and l the distance between the poles, which is approximately the length of the magnet.

The magnetic repulsion may then be calculated from a consideration of Fig. 110, if the inverse square law be assumed.

There are two repulsive forces, each equal to $\frac{m_1 m_2}{d^2}$, opposed by two forces due to the cross-attractions, each equal to—

$$\frac{m_1 m_2}{(d^2 + l^2)} \times \frac{d}{(d^2 + l^2)^{\frac{1}{2}}} = \frac{m_1 m_2 \,.\, d}{(d^2 + l^2)^{\frac{3}{2}}}$$

The total repulsive force is therefore—

$$2m_1 m_2 \left[\frac{1}{d^2} - \frac{d}{(d^2 + l^2)^{\frac{3}{2}}}\right] = \text{F, say.}$$

In Fig. 109 are represented this force, F, up the plane, the weight of the magnet, mg, vertically downwards, the normal reaction, R, and the frictional force, μR, down the plane, where μ is the coefficient of friction.

The angle of tilt is small, so that usually R may be taken as equal to mg.

Resolving all forces parallel to the plane, it is found that—

$$2m_1 m_2 \left[\frac{1}{d^2} - \frac{d}{(d^2 + l^2)^{\frac{3}{2}}}\right] - \mu mg = mg \sin \alpha \quad . \quad . \quad (1)$$

If h is the height of the plane and L its length, the equation may be written—

$$\frac{2m_1 m_2}{mg}\left[\frac{1}{d_2} - \frac{d}{(d^2 + l^2)^{\frac{3}{2}}}\right] - \mu mg = mg \frac{h}{\mathrm{L}} \quad . \quad . \quad . \quad (2)$$

The results are then treated as follows: the expression in the bracket is calculated for each value of d, and is plotted on a graph against the corresponding value of h. The curve obtained is found to be a straight line, thus verifying the assumption of an inverse square law except for near approach, when the repulsive force between the magnets is found to vary simply inversely as the distance, thus showing that it is not then legitimate to think of the poles as points. Also demagnetising effects will then be greater. It is seen from equation (2) that when the term in the bracket is zero, $\mu = -\frac{h}{\mathrm{L}}$, and thus from the

intercept on the axis of h, the coefficient of friction may be determined, giving a value in fair agreement with that obtained by a direct determination.

For typical result, see *S.S.R.*, (XLVI) December 1930.

129. MAGNETOMETER

Birmingham, 1931

The magnet (chrome steel) is placed on the back of a half-silvered mirror, supported by a fibre of unspun silk. The suspension is continued beneath by a fine wire to a paper vane, which dips inside a glass tube for damping.

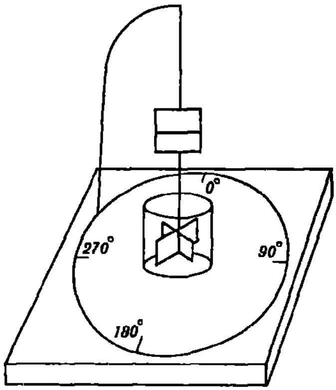


FIG. 111.

The scale is viewed obliquely from above, directly through the upper clear half and by reflection in the lower silvered half. When the magnet is oscillating, the image of the fixed scale rotates alongside the direct view of the scale. Orientation is fixed by the 0° and 180° coinciding.

The apparatus is surrounded by a bell jar, preferably resting on the wooden base.

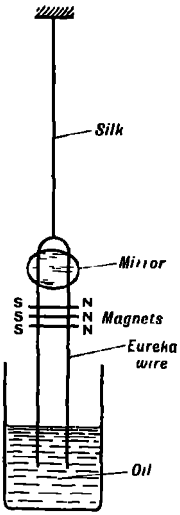


FIG. 112.

130. DEAD-BEAT MIRROR MAGNETOMETER

S. R. Humby

A dead-beat mirror magnetometer is particularly useful for demonstrations

of the properties of magnetic materials and for experiments on hysteresis.

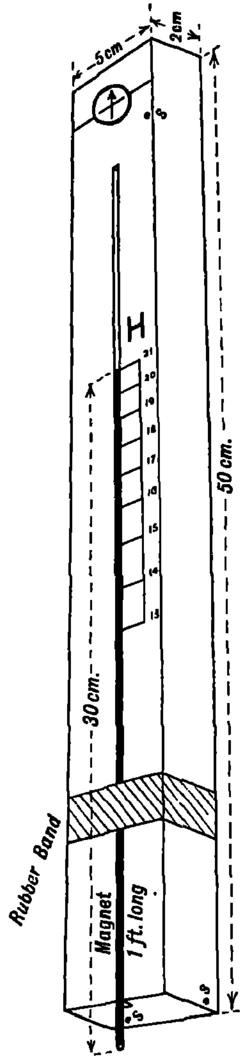


FIG. 113.

The instrument is enclosed in a glass-fronted case to prevent disturbance from air currents.

131. THE GAUSSMETER—CONSTRUCTION

F. A. Meier

The Gaussmeter is an instrument which will measure directly the value of the horizontal component, H, of the earth's magnetic field.

The most important part of the apparatus is a small *good* compass needle, jewel mounted, with small cross-bar and glass on both sides; this may be obtained for 7*s*. 6*d*. from any of the well-known makers. It is a standard pattern. *An inferior needlc will not give the results specified.*

The compass is fixed in one end of a piece of wood, about $50 \times 5 \times 2$ cm. (Fig. 113). A narrow central groove is made in the wood, on which is placed a cobalt-steel magnet of dimensions 1 ft. $\times$ $\frac{3}{16}$ in. diameter. The instrument is set approximately in the magnetic meridian at the place where H is to be found. The S end of the magnet is slowly made to approach the compass needle. If the earth's field exceeds that of the

magnet, the needle will point north, and if the magnet's field is the greater, the needle will point south. When the two fields are equal, that is, when the needle is at the "Null" point, the needle will set approximately at right angles to the meridian if the instrument is gently rocked and the needle made to oscillate slightly so that friction is reduced to a minimum. One of the three small round-headed brass screws, S, in the base under the needle serves as a pivot for a slight rocking motion.

A change in the field of $\frac{1}{100}$ of H can be detected by such a compass needle, and a movement of the long magnet of less than 1 mm. at a distance of 20 cm. is enough to cause a distinct movement of the needle, provided it is made to oscillate slightly, as already explained.

132. METHOD OF CALIBRATING THE GAUSSMETER BY MEANS OF THE CALIBRATION CURVES

F. A. Meier

Before the instrument can be calibrated, it is necessary to know the value of *H in one place*, in the laboratory, or in the open air, to an accuracy of 1 per cent. The value in the open air for any place in England may be taken from the isomagnetic chart issued for the British Isles.

This chart was published in the *Transactions of the Royal Society*, Series A, Vol. 219, after the Magnetic

TABLE GIVING THE HORIZONTAL COMPONENT OF THE EARTH'S FIELD IN ENGLAND

Longitude.	North Latitude.							
	50°	51°	52°	53°	54°	55°	56°	57°
East 1° .	·192	·188	·184	·180	—	—	—	—
0° .	·191	·187	·183	·179	·175	—	—	—
West 1° .	·191	·187	·182	·178	·174	·170	—	—
2° .	·190	·186	·182	·178	·174	·169	·165	·160
3° .	·189	·185	·181	·177	·173	·169	·164	·160
4° .	·189	·185	·181	·177	·173	·168	·164	·159
5° .	·188	·184	·180	·176	·172	·168	163	·159

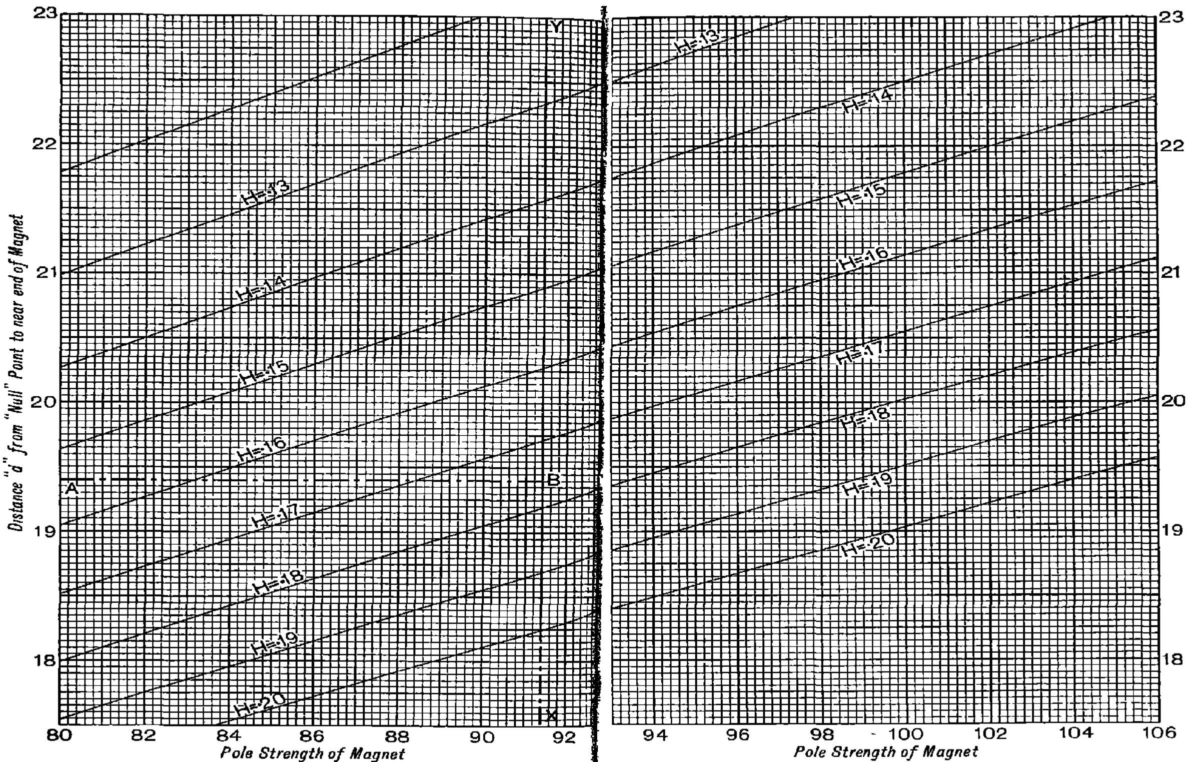

H=·13
H=·14
H=·15
H=·16
H=·17
H=·18
H=·19
H=·20
A
B
X
Y
23
22
21
20
19
18
80
82
84
86
88
90
92
94
96
98
100
102
104
106
Distance "d" from "Null" Point to near end of Magnet
Pole Strength of Magnet
Pole Strength of Magnet

Fig. 114.

Survey by George Walker in 1915. Since it may not be readily accessible to some, a short table has been given on p. 147 with the values of H in different parts of England for the year 1915. The annual decrease is about ·00011 gauss.

Having decided on the value of H, the instrument without the magnet is set in the meridian in the open air and the needle allowed to come to rest. The magnet is now adjusted until the needle sets at right angles. A mark is then made opposite the end of the magnet on a paper strip which has been pasted on the instrument. The rest of the calibration is merely a matter of reading off the sizes of the scale divisions on the curves as follows :

Suppose H = ·176, and that the near end of the magnet is 19·4 cm. (= d) from the centre of the needle when it has been set in the open to balance the earth's field. Draw a horizontal line, AB (see Fig. 114), for this value of d until it meets the curve for which H = ·176. Since curves have only been drawn for intervals of ·1 gauss, it may be necessary to estimate the point where B should approximately be taken. Great accuracy in choosing the position of B is not required, since the curves are so nearly parallel.

Through B draw a vertical line, XY. The points of intersection of the line XY with the successive curves give the position of the scale divisions. The numbers below give the distances as deduced from the curves :

"H" (in Gauss).	Distance d from Compass to Scale Division.
·20	18·24 cm.
·19	18·70 ,,
·18	19·18 ,,
·17	19·70 ,,
·16	20·27 ,,
·15	20·89 ,,
·14	21·57 ,,
·13	22·33 ,,

These distances are then marked on the strip of gummed paper on one side of the groove in the Gaussmeter. They are then numbered as in Fig. 113 and the calibration is complete.

Note to Fig. 114 (*pp.* 148–9)

It may be found that the magnets supplied by the makers are sometimes rather too strongly magnetised for use with these curves. Should that be so, they can easily be re-magnetised less strongly in a solenoid with either direct or alternating current without demagnetising them first. If direct current is used, care must be taken that the field in the solenoid is in such a direction as to reverse the magnetisation of the magnet.

A knowledge of the pole strength is not required when calibrating a Gaussmeter, and the figures for pole strengths marked along the **X** axis should not be used.

133. THE TWO "NULL" POINTS METHOD OF DETERMINING M/H

F. A. Meier

Till recently, the writer was not aware of the accuracy to which it is possible to locate the two "Null" points for a magnet lying in the magnetic meridian with its S pole pointing north; but the method, though not usually adopted, is certainly preferable to, and much less liable to error than, the ordinary school deflection magnetometer method used in the determination of H.

If a metre rule is placed in the meridian (see Fig. 115), and on it is laid a cobalt-steel magnet (10 cm., say, by ·6 cm. diameter), the positions of the two "Null" points may be found by slowly moving a compass needle, similar to that used in the Gaussmeter, towards the magnet, until it sets approximately at right angles to the meridian. Since both sides of the compass are glass, a reading of its position can be made to within ½ mm.; a movement of ½ mm. will be found to cause a visible movement of the needle. Tapping of the ruler is essential. The distance "2*d*" between the two "Null" points is then known *without any measurements being required for*

the position of the magnet. There are far fewer possibilities of errors in these two readings than when working with a deflection magnetometer. After some use in a school laboratory, these instruments often behave in a very uncertain manner, giving results upon which no reliance can be placed. Obviously the mass of the magnetometer needle and its pointer is considerably more than that of the small needle in the plotting compass, and the damage done to the fine point on which it turns is bound to lessen its sensitivity after much less use.

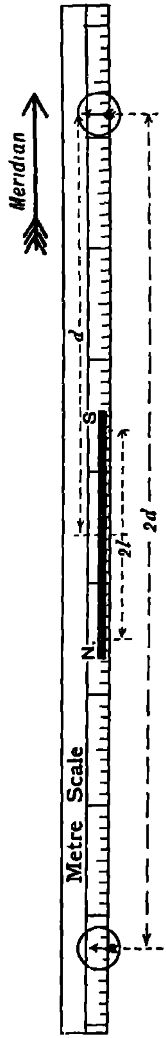


FIG. 115.

To show what accuracy may be obtained by careful work, the results of nine consecutive and quite independent experiments are given below. To prevent the observer from being biassed towards any particular reading, the position of the magnet on the scale was different each time, its position being chosen entirely at random. Care was taken that the table on which the work was done was free from magnetism.

Experiment.	"2d."
1	51·50 cm.
2	51·50 ,,
3	51·50 ,,
4	51·45 ,,
5	51·55 ,,
6	51·50 ,,
7	51·52 ,,
8	51·47 ,,
9	51·55 ,,
Mean =	51·50 ,,
Greatest deviation from mean =	·05 ,,

A claim that the error in the distance does not exceed 1 in 500 is justified without undue optimism.

Such results with an ordinary deflection magnetometer are highly unlikely, and, even if obtainable, require a far greater skill.

The value of M may then be calculated from the usual formula $\frac{2.M.d.}{(d^2 - l^2)^2} = H.$

The choice of a magnet is important. It should fulfil the following conditions :

(*a*) It must be long enough to make an accurate determination of its moment of inertia possible.

(*b*) It should have strong poles relative to its size, so that the distance between the two "Null" points is as great as possible.

(*c*) It should be short enough for any error made in locating the poles not appreciably to affect the calculated value of M/H.

(*d*) It should have a high coercive force, so that it does not lose any of its magnetism during the experiments.

(*e*) It should have a small diameter compared to its length, so that the poles are not too diffuse.

A magnet of cobalt steel, 4 in. long and $\frac{1}{4}$ in. diameter, satisfies these conditions.

The poles of such a magnet are about 1 cm. from the ends.

Difficulty is often experienced in suspending such a magnet for oscillation purposes. (See experiment 124, last paragraph.)

The usual oscillation experiment must be made to find the product MH. It may be as well to emphasise the fact that the double amplitude of swing should not exceed one-sixth of the magnet's length for the time of swing to be accurate to 1 in 500. It has also occurred before now that school magnetometer boxes are fastened together with iron nails or screws and covered with varnish. Such a fatality must, of course, be guarded against. The stop-watch is a frequent source of error, and it should certainly be tested, either by wireless time or against a

good watch, to see that its error does not exceed 1 second in 10 minutes. A small point, often not attended to, is to time the oscillations when one edge of the magnet is passing through the central position—denoted by a mark or other guide.

134. EXPERIMENTAL CONSTRUCTION OF THE GAUSSMETER SCALE

F. A. Meier

Assuming that the value of H is known at one spot in the laboratory and also the magnetic moment of the magnet used in the experiment, we may now either use the calibration curves (Fig. 114), or we may construct the scale for the Gaussmeter experimentally as follows :

Let us suppose that the value of H was ·172 gauss—this value having been obtained by the method described in experiment 133, or by comparing the times of oscillation of a magnet in the open and in the laboratory : the field in the open being given in the table on p. 147. Place the Gaussmeter in the meridian, and the magnet M, of known magnetic moment at such a distance, r, from the centre of the needle that it produces a field of ·008 gauss to supplement the earth's field and brings the total field up to ·180 gauss (see Fig. 116). The value of r is easily calculated with sufficient accuracy from the approximate formula $\frac{2.M}{r^3} = \cdot 008$.

Now adjust the position of the magnet AB until the needle of the Gaussmeter sets at right angles to the meridian (remember to make the needle oscillate slightly, as previously explained) and make a fine mark opposite the end B on a strip of paper gummed to the base-board, and intended for the scale.

Repeat this procedure several times, supplementing or diminishing the earth's field by amounts which will make the total field ·16 and ·20, etc. Three points are really

sufficient for an accurate curve to be drawn, since it is of very slight curvature, and the other values can be interpolated. The curve is best drawn by the aid of a steel ruler, which is bent to pass through the points. It is difficult for one person to do this.

It is not necessary to know the magnetic moment of the magnet used for altering the value of the field to an accuracy of more than 3 per cent., for it is used only for producing a small additional or subtractive field, and a 3 per cent. error in this does not affect the total field by even 1 per cent.

The Magnet that is used with the Gaussmeter.—It is essential that the magnet used with the Gaussmeter should permanently retain its magnetism. For this reason, a cobalt-steel magnet of high coercive force is chosen. To diminish the demagnetising effect of the poles, the magnet is long and of small cross-section (1 ft. × $\frac{3}{16}$ in. diameter). It need hardly be added that it should not be allowed to come into contact with other magnets, nor be brought into powerful magnetic fields such as are liable to be encountered near an electromagnet, motor or dynamo.

The constancy of the magnetic moment of a long thin bar magnet depends on a great many factors. The magnet suffers a loss after magnetisation, at first relatively rapid, but after some time the rate of decay becomes negligible. Mechanical shock of any kind reduces the pole strength. Tapping the magnet with a hammer longitudinally after magnetisation has a tendency to "age" the magnet and bring its molecules into a steady state. Cobalt-steel magnets seem to lose about 1 to 2 per cent. of their magnetisation when thus hammered, and to be then more resistant to shock.

It is *not necessary to locate the position of the pole* of the magnet. Such magnets usually have poles between 1 and 1·5 cm. from the ends; this amount of variation is not sufficient to cause errors that need to be taken into account, since one point on the scale of the Gaussmeter

is always found experimentally even when the calibration curves are used.

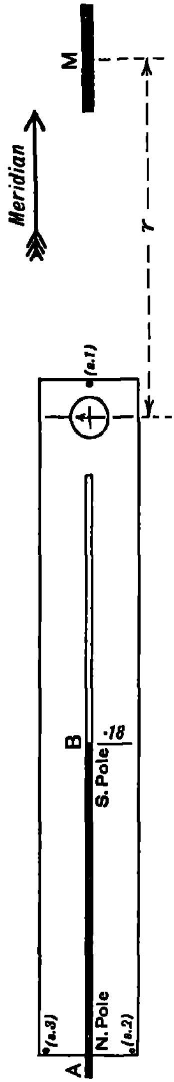


Fig. 116.

135. TO RECONDITION THE GAUSSMETER

F. A. Meier

It is almost impossible to guard against the magnet belonging to the Gaussmeter accidentally coming into contact with other magnets. Should it do so, and you suspect a change in its pole strength, it can at once be ascertained by setting the Gaussmeter at the point in the laboratory where H is known, and seeing if it gives the correct reading. Should there be an error, it will almost certainly indicate a reduction in pole strength. Remagnetisation with a solenoid is then required. A convenient magnetiser has already been described in experiment 123. Any long coil, with half a dozen layers working off either direct or alternating current light mains, is suitable. A rheostat must be used, and by the method of trial and error the right current can soon be found. It is convenient to remember that the pole strength can be slightly reduced by hammering, and that it is not necessary to obtain exactly the same pole strength as the original magnet, for the scale divisions alter only very slightly as the pole strength varies. This can be seen by looking at the curves in Fig. 114, pp. 148–9. They are nearly

into which it is divided by the curves. A copy of the old scale, pasted on in a slightly altered position to suit the new magnet, will still give readings within a 1 per cent. accuracy.

136. THE MAGNETIC MOMENT-METER

F. A. Meier

The construction of an instrument to measure directly the magnetic moment of a bar magnet involves a knowledge of H in one place in the laboratory where it is used. Such an instrument is obviously most helpful to the teacher, for it is the only possible way he has of quickly checking the value of magnetic moments.

Since H has already been ascertained when calibrating the Gaussmeter, this value can be used. Once again we adopt the principle of moving a magnet, lying in the meridian, towards a compass needle until the magnetic force of the bar magnet balances that due to H; this is indicated by the needle setting, or tending to set, at right angles to the meridian.

Constructional Details.—A compass needle of the same type as that used in the Gaussmeter is fixed at the end of a board about $55 \times 9 \times 2$ cm. A central rectangular groove, about 2 cm. wide and 1 cm. deep, is made in the board, into which fits a slider carrying the magnet.

If difficulty is found in making such a slot, it can be overcome by fixing two strips of wood on to a base-board, leaving a 2-cm. gap between them. The slider, about 14 cm. long, has a central groove and a strip of squared paper divided into cms. along one side of the groove with an arrow at the centre. It is then quite easy to set the magnet with its mid-point opposite the arrow. The instrument is set in the magnetic meridian, and the slider is moved until the needle sets at right angles to the meridian. Three small round-headed brass screws should be fixed to the bottom of the base-board so as to give three-point contact with the table, one screw being near the

compass end. The board can then easily be gently rocked to set the needle oscillating slightly in order to reduce friction.

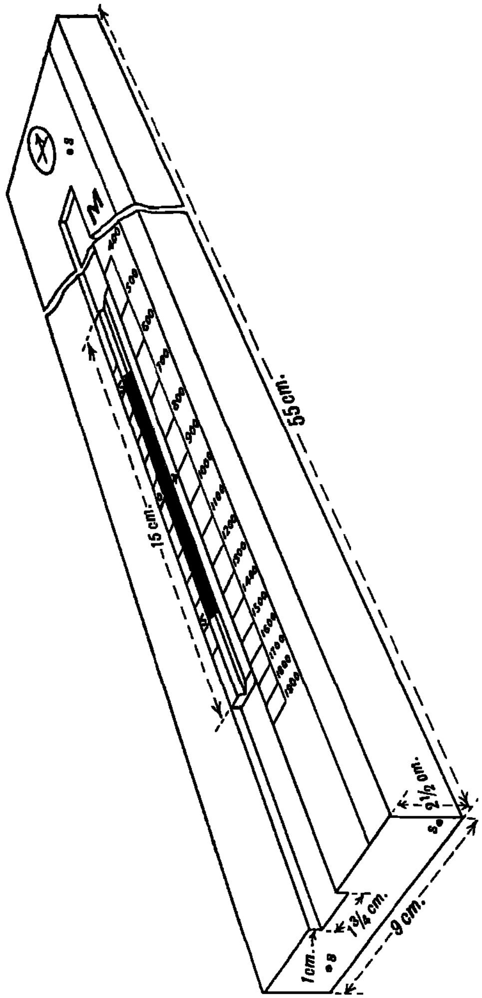


FIG. 117.

The number opposite the arrow on the scale indicates the value of the magnetic moment.

Theory of the Instrument.—For a very short magnet $\frac{2.M}{d^3} = H$, and the value of d can be immediately calculated for different values of M, taking for H the one known value that has been measured. In the table given below, the value of $H = \cdot 150$ has been used, and the last column gives the various values calculated for d, from which the scale of the instrument has been constructed, d being measured from the centre of the compass needle.

But, unfortunately, the formula $\frac{2.M}{d^3} = H$ is not true for magnets of finite length, and for the ordinary magnet used in magnetometry a correction has to be subtracted from the M shown on the scale.

These corrections for different lengths of magnets are

TABLE OF CORRECTIONS TO BE *subtracted* FROM THE SCALE READING TO ALLOW FOR THE FINITE LENGTH OF THE MAGNET (THE LENGTH BEING APPROXIMATELY THAT BETWEEN THE POLES)

Magnetic Moment. M.	Length of Magnet.				Distance "d" from Centre of Compass to Scale Division.
	6 cm.	8 cm.	10 cm.	12 cm.	
400	25	40	65	95	17·48
500	25	45	70	100	18·82
600	25	50	75	110	20·00
700	30	50	80	115	21·06
800	30	50	80	120	22·02
900	30	55	90	125	22·90
1,000	30	60	90	130	23·71
1,100	30	60	90	130	24·47
1,200	35	60	95	135	25·20
1,300	35	60	100	140	25·88
1,400	35	65	100	145	26·53
1,500	35	65	100	150	27·14
1,600	35	65	105	150	27·73
1,700	40	70	105	150	28·30
1,800	40	70	110	155	28·85
1,900	40	70	110	160	29·37
2,000	40	70	110	160	29·87

given in columns 2, 3, 4 and 5 of the table on p. 159. They are given only to the nearest 5 or 10, since this is sufficiently near to give the whole moment within a 1 per cent. accuracy.

The table of corrections is pasted on one end of the instrument.

Method of calculating the Corrections.—The true value of the magnetic moment (say, M_o) should have been calculated from the usual formula $\frac{2.M_o.d}{(d^2 - l^2)^2} = H$. Actually, the values of M were obtained from the formula $\frac{2.M}{d^3} = H$. Therefore there is an error in the moment, which I shall call "e."

$$\text{Hence } \frac{2(M + e).d}{(d^2 - l^2)^2} = H.$$

$$\therefore \qquad M + e = \frac{(d^2 - l^2)^2.H}{2.d}.$$

$$= \frac{H.d^3}{2} - d.l^2.\ H + \text{a small term.}$$

$$\text{But} \qquad \frac{H.d^3}{2} = M.$$

$$\therefore \qquad (M + e) = M - d.l^2.H.$$

$$\therefore \qquad \text{Error } e = -\ (d.l^2.H) \text{ approx.}$$

For example.—If the scale reading $M = 1{,}200$, with a magnet of about 8 cm. between the poles, the correction given in the tables is $-$ 60. This is the product of $d.l^2.H = (25{\cdot}20 \times 4^2 \times {\cdot}15) = -\ 60$. It is not necessary to know the position of the poles to any great accuracy, since the correction is small compared with the whole magnetic moment M. For most magnets used in magnetometry, especially those of cobalt steel up to $\frac{3}{8}$ in. diameter, it is near enough to consider the centre of the pole as 1 cm. from the ends.

The instrument here described will give readings to

1 per cent. if carefully used. It is obviously intended only for the teacher ; it will greatly stimulate the interest taken in quantitative magnetism. It is essential to note that the corrections given in the table on p. 159 must be multiplied by the factor $\frac{H}{\cdot 15}$ when used in a magnetic field differing from $H = \cdot 15$ (H being the value of the field where the instrument is to be used). The column giving the values of d must also be multiplied by a factor, viz. $\sqrt[3]{\frac{\cdot 15}{H}}$, since d was originally calculated from the formula $d = \sqrt[3]{\frac{2M}{\cdot 15}}$.

If the instrument *is used with the table of corrections given on* p. 159, in a place where H is *not* ·15, then the value of the magnetic moment obtained must be multiplied by the factor $\frac{H}{\cdot 15}$. A correct table should be made with a slide rule, for the various multiplications can be done in a few moments.

MAGNETOSTRICTION

137. ELONGATION OF AN IRON BAR

Rev. W. Burton

A rod of iron, about 1 yd. long and ½ in. in diameter, is wound round with two or three layers of No. 22 cotton-covered copper wire to within 1 in. of each end. One end rests on a block of wood and is clamped to the bench ; the other end rests on the shorter arm of a bent pointer. This is made by drawing out a piece of glass tubing to less than 1 mm. in diameter and bending it at right angles. The longer arm is about 30 cm. long and is vertical. When the iron is magnetised, the increase in length is shown by the movement of the tip of the pointer over a graduated

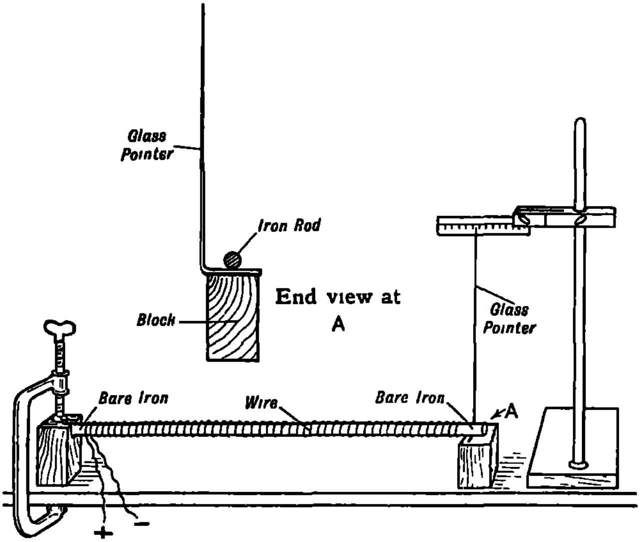


FIG. 118.

mm. scale, pasted on a strip of mirror glass and held in a burette stand.

138. ELONGATION OF AN IRON BAR

W. H. Topham

A long iron bar is supported in a vertical position on an ordinary retort stand, and its lower end, which should be resting on the base of the retort stand, is connected with a battery and either a mirror galvanometer or, by means of a relay, with an electric bell. A screw with very fine pitch, e.g. a spherometer, is clamped just above the upper end of the bar, and is also connected up to the battery. The screw is carefully adjusted until it just does not make contact with the bar. The bar has previously been wound round with a coil of wire by means of which it may be magnetised. On doing this, the mirror is deflected, or the bell rings, showing that the bar has elongated and made contact with the screw.

On cutting off the current, these results cease. The expansion due to heating may be eliminated by using an iron tube traversed by a current of water in the place of the iron bar.

MAGNETIC POLES

139. METHOD OF LOCATING THE POLE OF A MAGNET ACCURATELY

F. A. Meier

The ordinary method of using a compass needle and producing the lines to meet or form a small triangle of

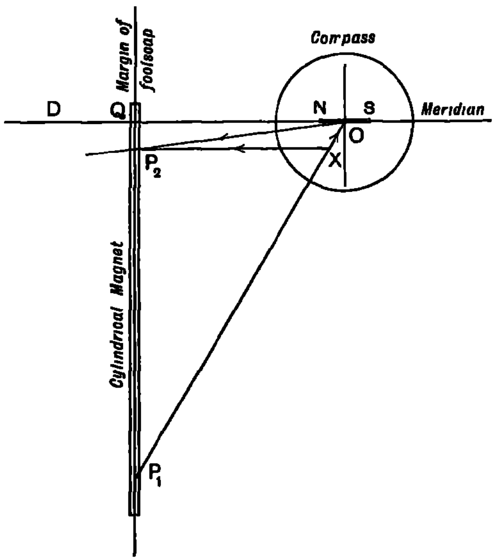


FIG. 119.

which the centre is taken is quite unreliable. This method may lead to errors up to 0·6 of a cm. for the position of each pole, and errors up to 8 per cent. for the pole strength. The magnitude of this error outweighs all the others, and it is suggested that the following

method be adopted for ascertaining the position of the pole when a pole strength is to be accurately measured.

Place a *good compass needle* on a piece of lined foolscap with the lines of the paper pointing in the magnetic meridian (Fig. 119).

Now place the magnet along the margin of the paper in the position shown in Fig. 119, in such a position that the needle is not deflected from the meridian. The end of the magnet will not necessarily lie on the line DO, and the amount by which it overlaps must be noted.

Arrange that QO is about one-third the magnetic length of the magnet.

The two forces due to the poles P_2 and P_1 can be represented by the lines P_2O and OX in the figure, where $P_2O = 9$ times OX. Their resultant must, of course, be parallel to the meridian.

Now $\frac{P_2O}{OX} = \frac{QO}{QP_2}$ (approximately to an accuracy of 1 in 20). This can be verified by drawing or admits of a simple proof.

Hence $QP_2 =$ one-ninth of QO.

The distance of the pole P_2 from Q is therefore one-ninth of the distance of Q from O.

If a greater ratio is chosen for the distances from the poles to O, say 4 to 1, the true pole P_2 will be one-sixteenth of QO along the magnet from Q. The total distance of the pole from the end will be QP_2 plus the small overlap of the magnet beyond the line DO. The error made in locating the pole by this method is less than half a millimetre. *Not a single line need be drawn, and all calculation can be done mentally in a few seconds,* though it has taken a long time to describe the details of locating the pole. Only an approximate knowledge of the position of the poles is assumed in this method, and it is unlikely that errors greater than 1 in 30 are made in the lengths QO and P_1O. P_2O is very nearly equal to QO, and the latter is much more conveniently measured when setting the magnet.

In determining the position of the poles, the compass needle may be placed at a distance of not less than 4 cm. from one pole of the magnet. I am not aware of any other method by which it can be located with sufficient accuracy to avoid errors up to 8 per cent. For a 12-cm. cylindrical magnet of $\frac{1}{2}$ cm. diameter, the ordinary way of getting the pole with a compass needle leads to a magnetic length that is about ·7 cm. in error.

140. RAPID DETERMINATION OF POLE STRENGTHS

F. A. Meier

A simple way of checking pole strengths rapidly is to use a sensitive galvanometer (such as the uni-pivot self-clamping type sold by Messrs. Pye & Co., which has a sensitivity of about 1 micro-ampère per division) in series with a small coil of, say, 100 or 200 turns. This coil should slide loosely over the magnet. The magnet is pushed half-way into the coil and the galvanometer allowed to come to rest. The magnet is then rapidly withdrawn and the kick of the galvanometer noted. In this type of instrument, the kick is very accurately proportional to the number of lines of force that have been cut by the coil. I have repeatedly tested this by a Grassot Fluxmeter and append the results for such an instrument taken at random.

Galvanometer kick with different magnets.	Fluxmeter reading, giving number of lines of force emerging from each pole.	Ratio of Fluxmeter reading to Galvanometer kick.
7·5	25·5 × 100	3·38
14·8	50·0 × 100	3·40
26·0	87·5 × 100	3·36
39·4	135·0 × 100	3·43
		Mean = 3·39

Greatest variation only 1 per cent. from the mean.

The number of lines is, of course, proportional to the pole strength.

If, then, a single pole strength of any magnet be accurately known, and the kick of the galvanometer when this magnet is withdrawn from the coil, the constant for the instrument can be at once deduced. Henceforward it can be used as a fluxmeter for measuring lines or pole strengths, the constant for lines of force being 4π times that for measuring pole strengths.

In the galvanometer considered above, the factor for reducing the kick to number of lines of force is 339, and for reducing the kick to pole strength it is 339 divided by 4π, or 26·7.

There is no difficulty in reading the kick to one-tenth of a division after the right position for the eye has been found.

The problem therefore becomes one of finding once and for all the pole strength of a single magnet (see experiments 134 and 139) in order to be able to calibrate one or more galvanometers for future use to serve as fluxmeters. Only few laboratories will be able to afford a fluxmeter costing £20 to £30.

ELECTRICITY

ALTERNATING CURRENT

141. THE FREQUENCY OF AN A.C. SUPPLY

W. E. Pearce

First Method.—The apparatus (Fig. 120) consists of a vibrator, AC, a magnetising bobbin, B, and a U-shaped magnet, M. The vibrator is a steel knitting needle which has had one end hammered out slightly and drilled with

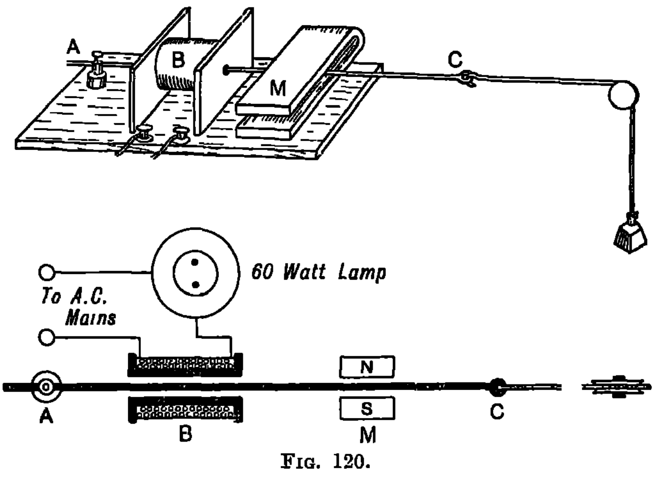


FIG. 120.

a fine drill so that a length of cotton can be attached to it. The other end is passed through the bobbin and through an ordinary wood screw terminal, A, so that it can be clamped at any point along its length. The bobbin is 1 in. long, with a central hole $\frac{1}{4}$ in. in diameter, and is wound with 150 turns of No. 28 D.S.C. copper wire. This

coil is connected in series with a 60-watt lamp, so that the circuit can be connected directly across the mains.

One end of a length of cotton is attached directly to the vibrator, and the other end passes over a pulley and has weights attached to it. When the alternating current flows through the coil, the free end of the vibrator is magnetised alternately N and S. It is attracted first to one pole of the permanent magnet and then to the other, so that a continuous vibration is set up. The vibrating length is adjusted until maximum amplitude results, which is the condition for resonance.

The vibration is imparted to the stretched string, which vibrates transversely in segments. The length of the string, or the load, can be adjusted until the nodes are clearly marked. The wave-length can then be determined.

Hence we can find n, using the usual formula :

$$n = \frac{1}{\lambda}\sqrt{\frac{t}{m}} \quad \text{where } n = \text{frequency}$$

$$\lambda = \text{wave-length}$$
$$t = \text{stretching force}$$
$$m = \text{mass per unit length.}$$

It is most interesting to stretch the string the whole length of the laboratory, since this increases the number of segments.

Typical Results obtained with Experiment :

Length of string = 818 cm.

Mass of string = ·5289 grams.

Mass per unit length of string = ·0006466 grams per cm. length.

Tension in string .	28·1 grms. wt.	33·1 grms. wt.	38·1 grms. wt.	43·1 grms. wt.	48·1 grms. wt.	53·1 grms. wt.
No. of loops	25	23	22	20·25	19·5	18·25
Frequency .	99·72	99·56	102·2	100·1	101·7	100·1

Average frequency of supply = 100·56.

Length of string = 810 cm.
Mass of string = ·535 grams.
Mass per unit length of string = ·0006605 grams per cm. length.

Tension in string .	35 g.w.	40 g.w.	45 g.w.	50 g.w.	55 g.w.	60 g.w.	70 g.w.
No. of loops	22·75	21	20	19	18·25	17·5	16·25
Frequency	101·3	99·93	100·9	101·1	101·8	102	102·1

Average frequency of supply = 101·3.

Second Method.—A bobbin, B (Fig. 121), is wound with 1,500 turns of No. 28 D.C.C. wire and fixed in the clamp of a retort stand. This winding is joined in series with a 60-watt lamp and connected to the A.C. mains. A piece of No. 20 soft-iron wire, AD, 2 in. long, is hammered out at the ends, and in each of the two flat portions so formed a small hole is drilled, or the iron may be heated and the holes punched out by a sewing-machine needle. A thread, CW (No. 60 cotton), has a weight attached to its lower end and passes through the small holes, D and A, as shown, and is then supported at C. The iron, AD, is just below the strongest part of the magnetic field. When the current is switched on, there is an upward magnetic pull on AD twice every cycle. These impulses are communicated to the cotton, which vibrates in segments. It should be noted that this method of generating vibrations is analogous to the so-called longitudinal arrangement of Melde, so that the frequency of vibration of the cotton will be equal to that of the supply. In general, the length, DW, will not be equal to an exact number of half wave-lengths, but a forced vibration of small

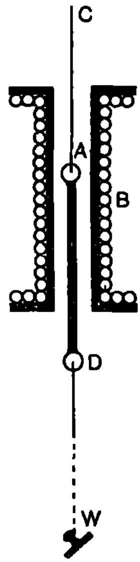


Fig. 121.

amplitude will usually occur. By moving the iron slider, AD, towards W and then slowly raising the thread at C, the conditions for maximum amplitude can be found and the wave-length for a given load measured. Then

$$n = \frac{1}{\lambda}\sqrt{\frac{t}{m}}.$$

Results :

Load = 10 grams weight.
Distance between nodes = 26·5 cm.
Length DW = 106 cm.
Mass per unit length = ·00034 grams.
$\therefore n$ = 101·3 cycles per sec.

142. THE FREQUENCY OF AN ALTERNATING-CURRENT SUPPLY

G. N. Pingriff

The following experiment can be carried out easily in any laboratory which has an alternating current electric supply. A length of about 4 ft. of fairly stout iron wire is clamped firmly at one end, and the other end is carried over a small pulley to a weight carrier by means of which the wire is stretched. A large solenoid with iron core (the " choke coil " often supplied for use with an arc-lamp is excellent) is then arranged so that the iron core comes to within about $\frac{3}{4}$ in. of the centre of the wire. The current is fed into the solenoid through a small resistance (or direct from the main with a large choke coil) and the tension of the wire adjusted until stationary vibrations are set up. The easiest mode of vibration to obtain is that in which the wire vibrates in three segments ; perfectly distinct nodes and amplitude of at least $\frac{1}{2}$ in. at the antinodes are seen. The tension is then made nine times what it has been, and the wire at once vibrates with larger amplitude in one segment.

A length of the wire is then weighed and the frequency obtained from the usual formula $n = \frac{1}{2l}\sqrt{\frac{T}{m}}$. The frequency of the current is then half the value so found for n. The experiment works well, and the student will learn a good deal in finding the reasons for each of the above steps.

Many variations in the method of conducting the work will be apparent.

143. A SIMPLE FORM OF ALTERNATING-CURRENT VOLTMETER

James Taylor

A voltmeter for measuring A.C. voltages of from 10 volts upwards may be constructed in a simple manner.

An ordinary three-electrode radio valve is taken, and the plate and grid are short-circuited (see Fig. 122). The plate terminal is connected in series with a high resistance (carbon resistances such as are used for wireless purposes are suitable), and microammeter, as shown. The filament, F, is connected in series with a battery of accumulators of the requisite specified voltage for maintaining the filament at the correct functioning temperature, while the negative end of the battery is connected to a terminal, A. If now an alternating voltage is applied to the terminals A and B, the instrument M registers a current. R is usually of the order of a megohm if M is a microammeter and A.C. voltages of about 10 to 200 are to be measured.

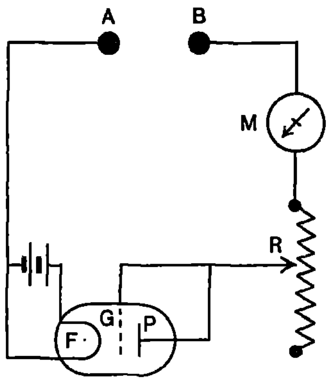


FIG. 122.

The major part of the potential drop at any moment is along the resistance, R, of which the value is great compared with that of the valve ; consequently, the valve acts as a very efficient rectifier when used on A.C. voltages.

The instrument is calibrated on D.C. voltages, and a chart is drawn up showing the microammeter readings corresponding to given voltages. If the currents in the chart are all halved in value, then the calibration applies to A.C. voltages (R.M.S. values).

If the value of R is suitably chosen, it may be arranged to read directly the R.M.S. values of the voltages. The scale is open, which is a great advantage, and by having a few interchangeable resistances, the range of the instrument may be altered at will. The calibration is also independent of the valve used. This may be replaced at will by another.

The theory and corrections are given in *Journ. Scient. Instrs.*, Vol. III, p. 113, 1925, to which reference may be made.

144. A LIQUID CURRENT INTERRUPTER

M. Finn

A test-tube, T, preferably of silica glass, in the lower end of which a small hole has been made, passes through a cork, C, in the centre of the block of wood, W, covering the top of the glass or earthenware jar, J. A brass terminal clamp, B, is screwed to a wooden cross-piece carried by two upright pieces of wood fixed to the block, W. A lead rod, L, held in the clamp, B, dips in the test-tube. A strip of lead, S, bent in the shape of the letter U, and provided with a terminal clamp, is placed in the outer vessel, J. Dilute sulphuric acid may be used.

The strength of the solution is gradually increased by slowly adding strong acid until the best effect is produced.

To keep the liquid cool, the interrupter is placed in a pail containing cold water.

The larger the hole in the test-tube, the stronger is the current required to exhibit the throttling action. A rheostat of about 5 ohms resistance, to carry about 10 amps., may with advantage be placed in series with the interrupter. The apparatus may be made at a trifling cost and is a very good substitute for the Wehnelt break. The action of the latter has been variously explained, but, in the writer's opinion, it is the same as that described in connection with experiment 127.

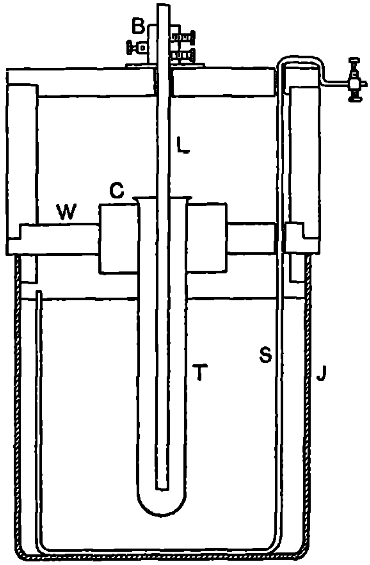


FIG. 123.

To use the interrupter with an ordinary induction coil, the contact breaker is screwed up tightly so that it cannot vibrate. The primary terminals, the interrupter and the rheostat are connected in series to the mains.

Like the Wehnelt break, this interrupter requires a certain inductance in the circuit.

The repulsion of an aluminium or other metal disc or ring from the end of a straight-core electromagnet may easily be shown by connecting the coil of the electromagnet in series with the interrupter.

AMMETERS

145. AN EASILY MADE HOT-WIRE AMMETER

G. N. Pingriff

The construction of this should be sufficiently obvious from the sketch. The spring is fixed at the bottom to

a wooden bridge, under which the heated wire passes, and at the top to the pointer (a half-metre scale); or an adjustable head may be used if preferred, this being

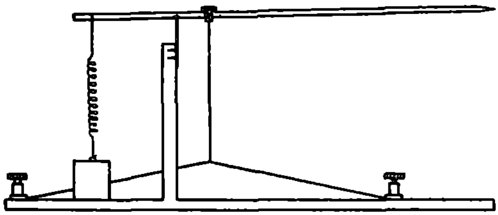


FIG. 124.

convenient in bringing the pointer to the zero on the scale. With constantan wire of No. 22 S.W.G., the instrument is suitable for measuring fairly heavy currents, such as taken by an arc-lamp, motor or electric heater; but with somewhat finer wire it will, of course, serve for smaller currents.

146. A HOT-WIRE AMMETER TO READ TO 0·25 AMPÈRE

W. E. Pearce

Stretch a piece of copper wire, AB (No. 20 S.W.G.), between two stands which are placed on the bench 9 ft. apart. From the centre of the wire attach a thread which passes around a pulley, P, and then supports a small weight, W (1 lb.). Solder a piece of wire to the pulley to act as a pointer and fix a protractor to the axis of the pulley to act as a scale. The copper wire is connected in series with an ammeter and a variable resistance, and hence with the mains. Pass the current through the wire and note the movement of the pointer owing to the expansion of the wire and the pull of the weight on the thread. A readable deflection should be obtained with $\frac{1}{4}$ of an ampère. A current of 5 amps. moves the pointer to a nearly vertical position, but it should be noted that

it takes some time to reach its final reading. When the current is cut off, the pointer should return to its zero

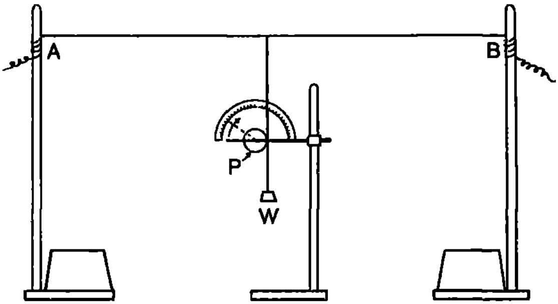


FIG. 125.

mark. Draw a graph showing the connection between the strength of the current and the position of the pointer, and use it to find the current taken by an arc-lamp or a bank of lamps.

CELLS

147. A STANDARD CELL OF LOW E.M.F.

C. R. Darling

This cell is based on the thermo-electric properties of fused bismuth, as explained in a paper read by Messrs. Darling and Grace before the Physical Society on November 24th, 1916. A thermal junction of aluminium and bismuth is formed by inserting an aluminium wire into a mass of bismuth contained in a special crucible. A silica tube, about 30 cm. in length, enters the crucible at a level beneath the surface of the bismuth and connects with a similar crucible at its other end, the silica tube and second crucible being filled with bismuth. An aluminium wire inserted in the bismuth in the second crucible forms the cold junction. On heating the first crucible, the E.M.F. rises steadily to a value of approximately 15 millivolts, which is attained at the melting-point of bismuth (269° C.).

Further heating up to nearly 500° causes no change in E.M.F.; so that by keeping a Bunsen burner of suitable size under the vessel, a steady E.M.F. may be obtained indefinitely.

The uses of such a cell are (1) evaluating deflections on galvanometer scales; (2) measuring low E.M.F.s such as developed by thermal junctions; and (3) general purposes in which a low, steady E.M.F. is needed, and which otherwise has to be obtained from a voltaic cell by the use of a potentiometer arrangement.

148. A SIMPLE FORM OF WESTON STANDARD CELL

S. R. Humby

The E.M.F. should be within ·0002 volts of an N.P.L. standard and the internal resistance is about 1,000 ohms.

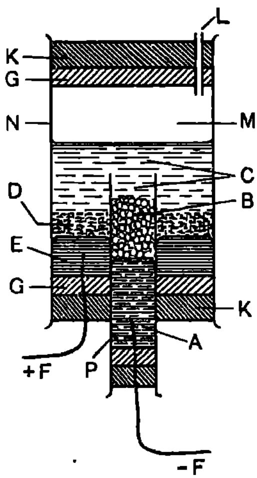


FIG. 126.

A = amalgam of mercury and cadmium (12·5 per cent. cadmium).
B = crystals of cadmium sulphate.
C = saturated solution of cadmium sulphate.
D = paste of mercurous and cadmium sulphates and mercury.
E = mercury.
F = platinum or iron-wire electrodes.
G = cork.
K = sealing-wax.
L = glass capillary air vent.
M = air space.
N = glass tubing, 2 in. long, 1½ in. diameter.
P = glass tubing, 1½ in. long, ½ in. diameter.

149. TO DEMONSTRATE THE BACK E.M.F. WHICH PRODUCES "POLARISATION" IN A CELL

S. R. Humby

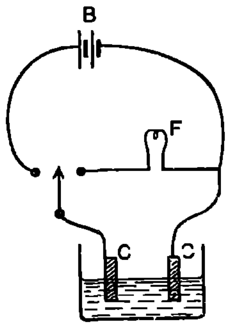


FIG. 127.

Two carbon rods, C, are placed in dilute sulphuric acid and connected as shown through a switch either to the 2-volt battery, B, or the flash lamp, F.

When the battery is switched on, gases are set free at the electrodes, and a back E.M.F. is set up. This will light the lamp for a few seconds when the switch to the lamp is closed.

CONDENSERS

150. SPECIFIC INDUCTIVE CAPACITY

E. Nightingale

A moving-coil ballistic galvanometer, G, is connected, as in the diagram, to one end of a change-over switch, A. The other end of the switch is connected to either 240-volt D.C. mains or to a 120–240-volt dry battery which stands on wax to ensure good insulation. The middle terminals of the switch are connected to a good wireless air condenser. An ex-army condenser is admirable for the experiment. The lamp, L, is inserted in the main circuit for safety. A is made of wax or ebonite or of sulphur-paraffin-wax. To eliminate "creep," the wires must be kept off the bench and the condenser must stand on an insulator.

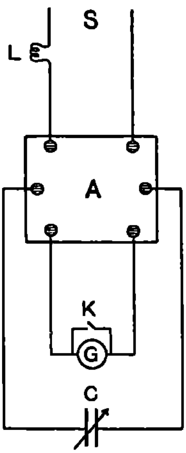


FIG. 128.

First charge the condenser by rocking the switch towards S, and then discharge through the condenser by rocking towards C. Do this two or three times for several settings of the condenser capacity. After each

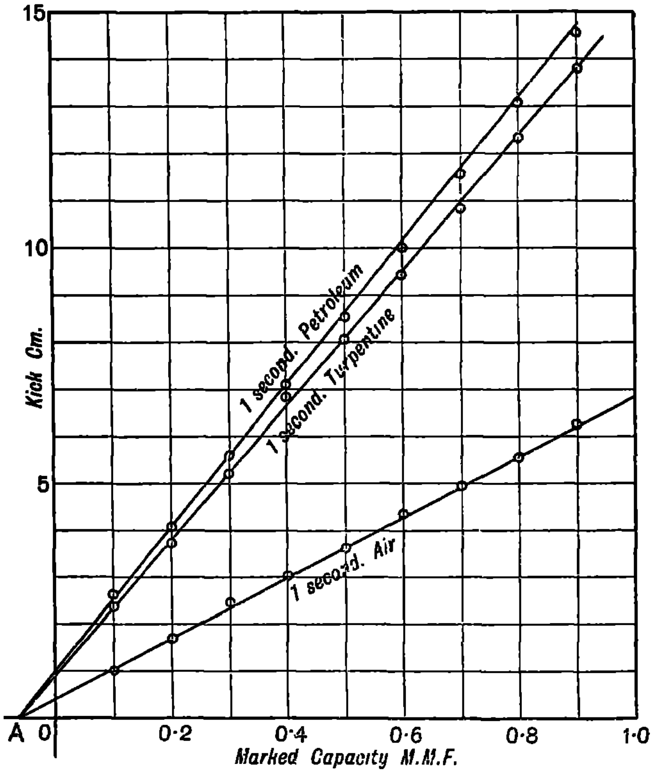


FIG. 129.

discharge, bring the galvanometer to rest by short-circuiting it through key, K.

Now fill the condenser with paraffin oil and repeat the experiment. Owing to the increase in specific inductive capacity, the readings are greater than before. Plot graphs showing the " kick " of the galvanometer against the marked capacity. These do not pass through the zero

of capacity, but through a point A (see graph). OA is evidently the capacity of the leads to the condenser. The graphs shown were obtained with an ex-army condenser, and from them the specific inductive capacity is found. It is the ratio

$$\frac{\text{Slope of graph for liquid dielectric}}{\text{Slope of graph for air dielectric.}}$$

The graphs shown give for petroleum 2·3 and for turpentine 2·1. The time of charge was 1 sec. in each case.

Warning.—Do not fill an aluminium-vane condenser with alcohol. This acts chemically on aluminium.

DIRECT CURRENT

151. A SMALL MOTOR GENERATING SET

W. E. Pearce

The number of schools capable of obtaining direct current from the mains is rapidly decreasing, and with the

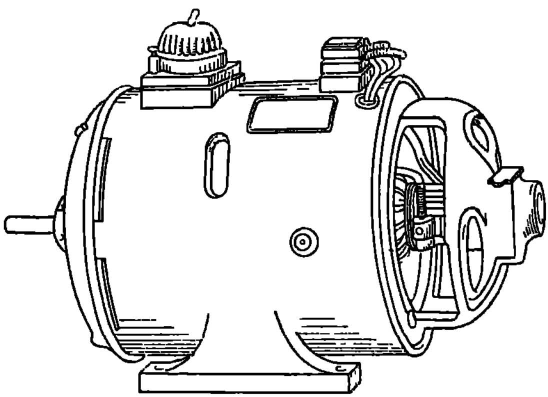


FIG. 130.

advent of the "Grid" system, most laboratories will be faced with the problem of converting A.C. to D.C. In my present laboratory, a small motor generator, obtained from

the Crypto Electrical Co., Ltd., Acton Lane, Willesden, N.W.10, has been used for over ten years with highly satisfactory results. The machine needs very little attention; in fact, during the above period, the only adjustment we have made is the altering of the setting of the carbon brushes on one occasion. On infrequent occasions the oil cups are filled. The cost of the machine to-day (1931) is £24 10*s*., and we incurred no expense in fixing it.

The machine consists of an A.C. motor and a D.C. dynamo running on the same shaft. The A.C. motor is of the squirrel-cage induction type, which is absolutely the most simple form of motor extant. On a single-phase supply, only two leads are necessary from the mains, and a suitable starting-switch is mounted with the motor. When ordering, it is necessary to state voltage, frequency and phase of supply. For single-phase the motor is provided with a starting and running winding, and all that is necessary to start the machine is for the starting coil to be put in circuit for a few seconds until the machine runs practically up to speed, when it is switched over to the running coils.

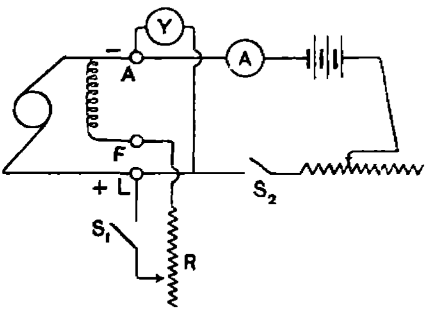


FIG. 131.

The dynamo is shunt wound and is provided with three terminals, marked A (armature), F (field) and L (line), as in the figure. If F and L are joined directly, the machine generates its maximum voltage, which, in our case, is 30 volts. If F and L are disconnected, the machine generates 1 to 2 volts due to residual magnetism. By placing a variable resistance, R, between these terminals, we can thus generate anything between

1 and 30 volts. The armature is wound to carry 7 amps. The machine makes very little noise when running, and if allowed to rest on a thick sheet of rubber does not interfere with teaching carried on in the same laboratory. Two or three inches of sawdust would possibly answer even better as a silencer. For class purposes, a 6-amp. fuse inserted in the circuit will effectively prevent the burning out of the armature by carelessness.

The machine is used for the following purposes :

(*a*) *Charging Accumulators.*—The diagram illustrates the necessary connections. The machine is admirably adapted for this purpose, since by means of the field-regulating resistance, we can vary the voltage generated and so dispense with a charging resistance. This method is economical, since we do not pay for the heat which would be developed in the latter resistance.

(*b*) *Demonstrations.*—Much time is saved, for permanent leads are run from the dynamo to the lecture bench, so that any voltage up to 30 volts is always instantly available. Moreover, with such a supply, demonstrations always seem to " work."

(*c*) *Class Use.*—A cable is run out from the dynamo and sub-switches made for each group. This is easily done by the boys. The voltage at each point is easily regulated, and a fuse at each switch prevents a careless boy stopping the work of the class. He merely pays the penalty for carelessness himself. If preferred, the cable could be run off a battery of accumulators.

The machine itself forms the basis of a number of experiments. The older boys are very keen about these, for they seem more practical than the usual laboratory experiments. The following are typical of the experiments that may be carried out :

(i) *Resistance of armature.*

This is a problem of finding a low resistance, and can be done by :

(*a*) Ammeter and milli-voltmeter.

(*b*) Potentiometer method.

The brushes must be insulated from the armature, and some means adopted of making efficient contact with the commutator strips. One method is to fix a gramophone needle into a connector joined to a lead. The needle is pressed hard into the commutator strip.

(ii) *Resistance of field coils.*

(iii) *Heating of field coils.*

The resistance of the field coils is found before the machine has been used, and then it is allowed to charge accumulators for five to six hours. The load is taken off, the machine is stopped and the resistance again found. Assuming the temperature coefficient, the rise in temperature can be found.

(iv) *Variation of voltage with resistance of field circuit.*

(v) *Variation of voltage with load.*

(vi) *Efficiency of machine under various loads.*

(vii) *To set up a circuit for charging accumulators.*

(viii) *To find the speed of the motor.*

The most usual method is by using a revolution counter, but the following is not without interest.

Neon Lamp Method.—Cut out a circular disc of white cardboard and draw a radius. Thicken this with Indian ink until it is $\frac{1}{4}$ in. thick. Enlarge the central hole of a wooden bobbin (e.g. one of those on which wire is sold) until it is a tight fit on the shaft of the motor. Pin the cardboard disc to the reel and start the motor. View the disc by the light of a neon lamp connected with the A.C. mains. In the case of the present machine, the black line looks like three radii of 120 degrees, and these all appear to rotate slowly in an anti-clockwise direction. By finding the time of an apparent rotation of a line and knowing the frequency of the mains, the speed of the motor can be calculated from the formula—

$$N = \frac{100}{3} - \frac{1}{t}, \text{ where } N = \text{Number of revs. per sec.}$$

and t = Time for an apparent revolution of the radius.

(ix) *To find the B.H.P. of the motor.*

The wire reel used in the last experiment can be used as a pulley, and a band looped over it in the usual way.

152. ELECTRICAL EXPERIMENTS USING D.C. MAINS

E. Nightingale

By means of a set of lamp boards of the type shown diagrammatically in Fig. 132, a whole class can use the supply mains for experiments. The "Lico" series

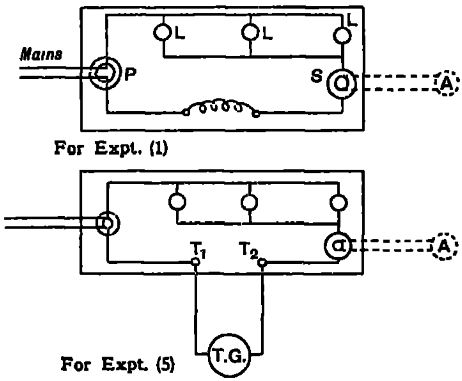


FIG. 132.

switch, S, enables an ammeter with a pinch plug to be inserted without breaking the circuit, and this makes it possible for several sets to use the same ammeter in turn.

Currents of various values are obtained by using different kinds of lamps in the holders. For small currents, neon lamps may be used, and for larger currents, metal and carbon filament lamps and radiator lamps are useful.

Possible experiments include the following:

(1) Resistances of lamps. (Given the voltage of the mains.)

(2) Resistances and specific resistances of wire by voltmeter-ammeter method.

(3) Laws of electrolysis.

(4) E.C.E. of metallic ions (e.g. Cu and Ni).

(5) Reduction factor of a tangent galvanometer (current read on ammeter).

(6) Finding "J."

(7) Solenoid experiments.

(8) Plotting lines of force about a straight wire and about a coil.

(9) Potentiometer principle. (Not, of course, with extreme accuracy.)

(10) Calibration of ammeter by comparison with standard.

(11) Calibration of galvanometer to read ampères.

(12) Pull of electromagnet.

The base-board is obtainable from any electrician, as are the holders.

ELECTROSCOPES

153. SIMPLE ELECTROSCOPE

Rev. W. Burton

This consists of a rectangular box of tinned iron or brass, with glass windows back and front. The glass windows are 2 in. apart, and are simply the cover glasses of lantern slides. The insulation is a piece of candle with the wick removed, which fits into a short tube, $\frac{3}{4} \times \frac{7}{8}$ in. diameter, soldered on to the top of the box over a circular opening in it $\frac{1}{2}$ in. in diameter. A 3-in. length

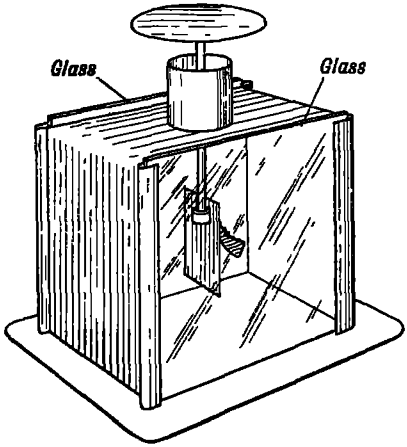


FIG. 133.

of screwed rod (2 B.A.) is screwed through the candle. The cap of the electroscope is a disc of metal, $1\frac{1}{2}$ in. in diameter, to the under side of which a 2 B.A. brass nut is soldered, and the plate to which the leaf is attached is a rectangular plate of metal, to the upper edge of which another 2 B.A. nut is soldered. If the insulation of the wax deteriorates, the upper layer of wax can be scraped off, or heated by passing the Bunsen flame over it. The rod can be prevented from slipping through the candle by screwing a nut on to the middle of the rod and sinking the nut into the wax. The electroscopes can be made in a school workshop.

154. ALUMINIUM-LEAF ELECTROSCOPE

S. R. Humby

Small aluminium-leaf electroscopes are found to give quite good results in simple quantitative measurements, and hold their charge without appreciable loss for over an hour. Deflections of the leaf ($2 \times \frac{1}{4}$ in.) are read with reference to a piece of squared paper cut to shape.

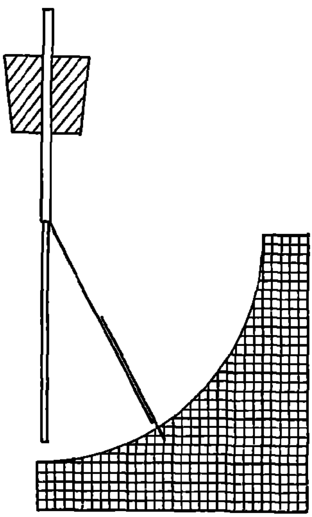


FIG. 134.

Leaf electroscopes are more easily read if very light pointers are attached to the aluminium leaf. To make the pointers, use a fibre of glass wool, or heat the middle part of 6 in. of thin glass tubing until it is very soft, and pull out quickly. The glass fibre so produced can be obtained so thin that it does not much affect the sensitiveness of the instrument when 1 in. of straight fibre is

attached to the leaf by using a trace of shellac or other adhesive.

In addition to the advantage of having a pointer on the leaf, the glass fibre keeps the leaf quite flat and rigid.

The scale readings are approximately proportional to the difference of voltage between the leaf and the case. It is sometimes convenient to calibrate the instrument as a voltmeter by joining the terminals of a high-tension battery, or of the electric-light mains, to the leaf and to the case; 200 volts should give a $\frac{1}{2}$-in. deflection of the leaf.

The capacity of other small insulated conductors can be tested relative to that of the electroscope by noting the deflections before and after the electroscope has been touched with the insulated conductor.

155. A SENSITIVE GOLD-LEAF ELECTROSCOPE

M. Finn

In the instrument shown in Fig. 135, the case is made of tinned iron or brass and is about 5 × 5 × 8 cm. high,

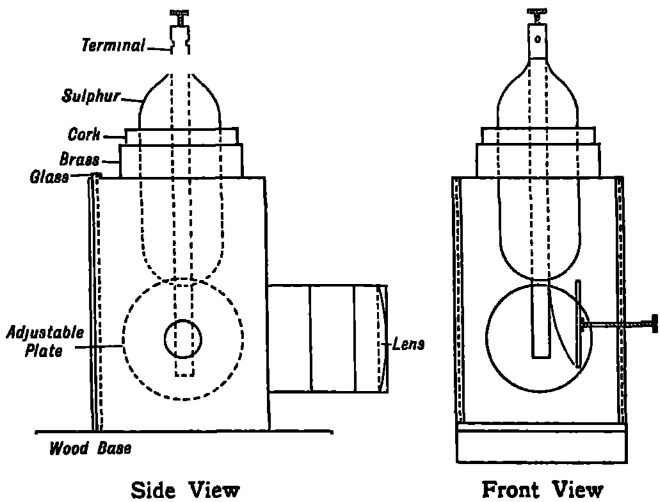


Fig. 135.

with a window at one end and an adjustable lens at the opposite end. The hole at the top of the case is about 4 cm. diameter, and is fitted with a cork for the leaf support. The latter consists of a thin brass tube with a terminal soldered on at the top and a strip of brass at the bottom. For insulation, a sulphur plug is cast round the middle of the leaf support. The gold leaf, about 2 cm. long and about 2 mm. wide, is attached with the merest trace of gum to the brass strip. Opposite the leaf, in the side of the case, is a vertical brass plate supported on the end of a horizontal screw, by means of which the distance (and the potential gradient) between the leaf and the plate can be adjusted. When the plate is very near the leaf, a noticeable deflection will be obtained with a couple of volts only, owing to the large potential gradient.

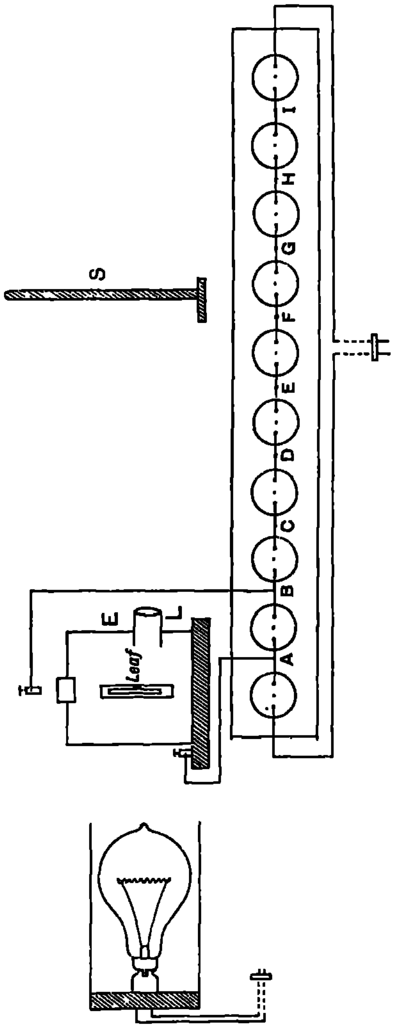


FIG. 136.

In the ordinary use of the instrument, care must be taken that the distance between the movable plate and the leaf support shall be just greater than the length of the leaf. To obtain the proper distance, hold the electroscope with the movable plate horizontal and turn the screw till the leaf is just clear of the plate. If a 100-watt gas-filled lamp be placed in front of the window, and the image of the leaf be focused on a screen of squared paper placed in front of the lens, "deflections" of the tip of the leaf can be accurately observed.

To calibrate the Gold-leaf Electroscope.—A board of ten lamp-holders in series is taken; lamps of equal candle powers, and therefore of approximately equal resistances, are inserted, and a current is passed. The voltage across each lamp is $\frac{E}{10}$, where E is the voltage of the mains. Similarly, the voltage across two lamps is $\frac{2E}{10}$, etc.

The gold-leaf electroscope is provided with a focusing lens, and a gas-filled lamp is used to illuminate the leaf. The lens is adjusted until the shadow of the leaf is clearly defined on the scale of squared paper, S. The case of the gold-leaf electroscope is connected to the first terminal, A, and the leaf system is connected in turn to B, C, D . . . I; each time the deflection is read off on the scale and the voltage noted.

156. AN ELECTROSCOPE FOR THE LECTURE TABLE

F. A. Meier

Description of Instrument.—Two ebonite caps, carrying lenses of focal lengths 5 cm. and 4 cm. respectively, fit into the ends of some telescopic brass tubing. The cap C_2 fits on to the inner tubing so that it can be used for focusing. A narrow strip of gold leaf, G ($1\frac{1}{2}$ cm. $\times$ 1 mm.), is attached to a brass rod which has either been filed or hammered flat at the end.

The lens L_1 has the same function as the condenser of a lantern, whilst the lens L_2 throws a magnified image on to the screen placed about 2 ft. distant. The lenses are held in position by two rings of stout brass wire, R.

Even in daylight (direct sunlight being excluded), a clear magnified image of the gold leaf may be obtained as

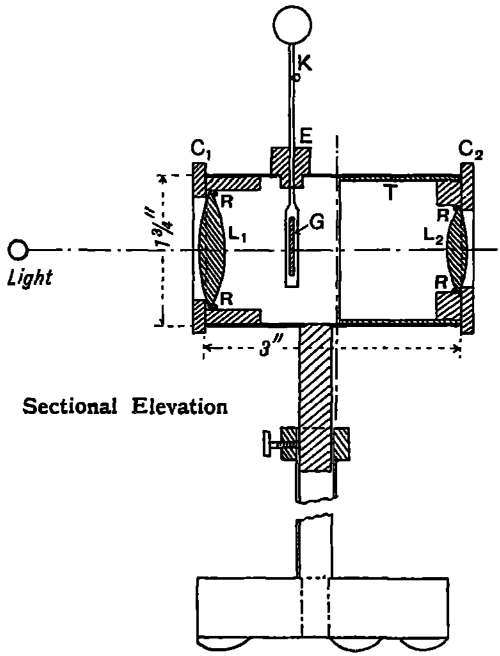


FIG. 137.

large as 6 in., and is easily seen by the whole class. The leaf moves over a graduated scale. The capacity of the instrument is very small and negligible in comparison with most capacities used in the lecture room. The heat from the condenser keeps the instrument dry, and even on wet days, after a few minutes, the instrument is in good working order and will retain its charge for hours without alteration. One hundred volts give a deflection of about 20 degrees.

ELECTROSTATICS

157. ELECTROSTATIC APPARATUS WITH SULPHUR INSULATION

S. R. Humby

Sulphur has very high insulating power, even in damp weather, and the material can be moulded and worked without difficulty. The apparatus made has been used successfully with a first-year course, and it is found that simple electrostatics experiments can then be done by the boys themselves.

Attention should be paid to the following practical details. Heat roll sulphur gently, and do not raise the temperature much above the melting-point. Moulds of wood or paper can be used. They must be really dry. The sulphur can be cut, filed or sawn quite easily if this is done directly after it has set and before it has cooled.

A circular sandwich (baking) tin, $8 \times \frac{1}{2}$ in. deep, filled with sulphur, makes an excellent insulating disc for an electrophorus. If the sulphur is taken out and replaced upside down, a very smooth surface is obtained. Small discs of sulphur, cast in shallow lids of tins, make good insulating stands.

Insulating handles for conductors are best made from ebonite rod, which will stand rough treatment.

158. SULPHUR-PARAFFIN-WAX INSULATION

E. Nightingale

The following insulating material is easily prepared.

Melt some wax in a tin and, when well above the melting-point, remove the flame. Stir in fine flowers of sulphur until the mixture is lumpy. This gives about 60/40 sulphur-wax. It should be immediately transferred to casting cases, or it may be worked into a hole in a cork with a knife. If too hot, the wax separates out. A little practice is necessary to get the best results.

Home-made electroscopes in which the gold leaves are insulated with this material will keep a charge for twenty-four hours. An electrophorus disc was made by heating the material in a baking tin and allowing to set. After rubbing with flannel, big sparks were obtained from the metal disc. The apparatus was put away with the disc on the cake. On being taken out a few days later, the disc gave strong sparks without the cake being rubbed.

The material is believed to be much better than ebonite or sulphur in regard to insulating properties.

159. POSITIVE ELECTRIFICATION

S.S.R., (VIII) 29

Cork is a handy substitute for silk for providing (with a glass rod) a source of positive electricity. The glass rod is positively charged after a few passages through a hole in a bark cork just large enough to admit it. The cork seems more efficient than silk. The same style of cork rubber charges ebonite negatively.

160. CHARGING AN ELECTROSCOPE FROM A FLAME

S. F. Dufton

The presence of charged particles in the flame and its products of combustion, inferred from the familiar discharging of electrified bodies by a flame, may be readily shown by placing a flame between an electroscope and a charged rod. On bringing up the rod, the electroscope is permanently charged with electricity of the same sign as that on the rod.

The flame must be insulated; if a candle is used, it should be placed on a paraffin block, or the lower end of the wick should be removed; otherwise the wick, being a fairly good conductor, provides an easier path for the

repelled electricity, which then escapes without being projected on to the electroscope.

161. THE LIGHTNING CONDUCTOR

S. A. Dyment

A discussion of the action of the lightning conductor invariably raises the question, " How do clouds become electrified ? " It is accepted, I believe, that the electrification associated with evaporation is among the possible sources, and the following experiment is worth showing. The idea is not entirely new. A small piece of metal is heated and placed in a tray (tin lid) on a gold-leaf electroscope, A. When tap water is allowed to drip on to this, the evaporation is accompanied by a divergence of the

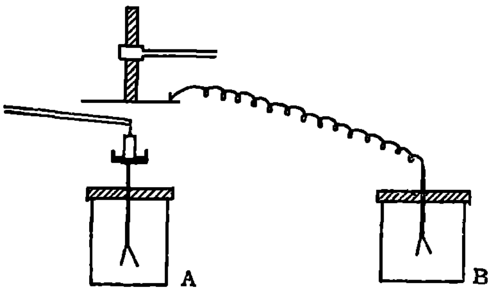


FIG. 138.

leaves. The effect is greatly increased by using a dilute solution of some salt ; common salt was the most effective of those tried. In almost every case the gold-leaf electroscope is charged negatively, and if the vapour is " caught " by a plate connected to another electroscope, B, this latter acquires a positive charge. Any moderately sensitive electroscopes will serve, but they should be tried beforehand. A small iron cylinder was used, heated to much less than red-heat ; if the evaporation is too vigorous, the effect is often obscured.

The intended action of the conductor itself can be

shown by attaching a long stiff wire, ending in a brush of finer wire, to a gold-leaf electroscope. When a charged ebonite rod is passed to and fro quite near to the brush, the electroscope acquires a charge similar to that on the rod, indicating an escape from the brush. A diminution of the charge on the rod can be shown by noting, before and after, the distances from a second electroscope at which it produces an equal divergence.

ELECTROMAGNETIC INDUCTION

162. TO SHOW THE PRODUCTION OF INDUCED CURRENTS

W. E. Pearce

Connect a coil, P, consisting of 100 turns of copper wire, in circuit with an ammeter, a regulating resistance and the A.C. mains. It is better if the coil has a sliding contact so that the number of turns used may be varied. The old-fashioned type of wireless aerial coil does excellently. Connect a similar coil, S, directly with a telephone receiver

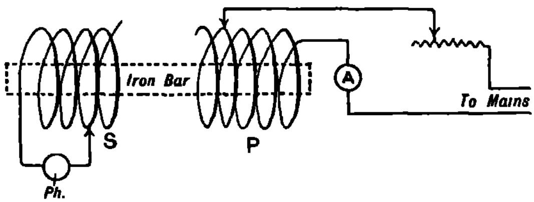


FIG. 139.

or loud speaker and pass 1–2 amps. through P. Note that the phone emits a musical note corresponding to the frequency of supply, and study the variation in loudness as the number of turns on both primary and secondary are varied and also as the distance between them is altered. If an iron rod from a retort stand is placed through the centre of each coil, the enhanced effect is remarkable. If a phone is not available, a 2-volt torch bulb may be used instead.

163. HEAT PRODUCED BY EDDY CURRENTS AND BY HYSTERESIS

W. E. Pearce

Wind a test-tube of 1 in. diameter with 100 turns of No. 20 D.C.C. wire. The coil thus made should be about 1 in. long and should be placed as near the bottom of the test-tube as possible. Fill the test-tube with steel ball-bearings until they are level with the top of the coil. Place a thermometer with its bulb in the ball-bearings and then pour in sufficient water to cover both. Pass a current of 5 amps. A.C. through the coil and note the rise in temperature in 5 mins. Allow the apparatus to return to room temperature and then pass 5 amps. direct current through the coil, and again take the rise of temperature in 5 mins.

Results :

I.	Current	= 5 amps. A.C.
	Rise in temperature in 5 mins.	= 10·1° C.
II.	Current	= 5 amps. D.C.
	Rise in temperature in 5 mins.	= 8·8° C.

FUSES

164. FUSING CURRENTS FOR VARIOUS WIRES

W. E. Pearce

Alternating current lends itself admirably to the demonstration of visible effects to boys who are taking a course of electricity for the first time and for whom the experiments are qualitative rather than quantitative. The following experiment is of this nature. Since currents up to 5 amps. are required, a preliminary precaution is to see that the fuse governing the supply to the laboratory is really suitable, or alternatively, a step-down transformer may be employed. The resistance of any one of the pieces of apparatus is low, so that 12 volts will be ample, and if the transformer is suitably wound, a current of 20 amps. could be used if desired.

Connect in series with the mains an A.C. ammeter, a regulating variable resistance and the wire under test. The latter should be stretched tightly between two supports about 3 ft. apart. The current should be slowly increased, and observations made of any change noticed in the condition of the wire.

TYPICAL RESULTS

Wire.	Current.	Note.
Iron Wire No. 22 S.W.G.	2 ampères	Sagging of wire showing expansion.
	3 ampères	Dull red colour.
	4½ ampères	White hot.
	5 ampères	Fusion with a shower of sparks.
Copper Wire No. 38 D.C.C.	1 ampère	Drying of insulation.
	2 ampères	Insulation smoulders.
	5 ampères	Fusion.
" 5-Ampère Fuse Wire "	2 ampères	No apparent result.
	4 ampères	Sagging of wire.
	5 ampères	Sudden melting of wire without sparks.

In the case of iron wire, the ammeter should be closely observed. For a particular case, the regulating resistance was reduced and the current rose rapidly to 5½ amps. without fusion taking place, but as the temperature of the wire increased, the current fell to 4½ amps. It required a very large reduction in the resistance of the circuit to produce a permanent current of 5 amps. This large temperature coefficient explains the use of iron wire in " baretters." These are often used to prevent the current in valve filaments exceeding certain values.

GALVANOMETERS

165. GALVANOMETER LAMP

D. G. A. Dyson

This is made of a square tube of three-ply wood, open at one end, and cut at an angle of 45° at the other in order

to take a plane mirror, which deflects the light from the lamp through a short focus (about 7 cm.) condensing lens, provided with a vertical wire. The advantage of introducing the mirror is that the tube, as a result, lies along the top of the screen, thus being more compact. The tube has two telephone terminals fixed as shown, and through these passes a $\frac{1}{8}$-in. brass rod, each end of which has been tapped to take a terminal (the shaft of which has been removed), which is locked on securely by a nut; care should be taken here to obtain terminals in which the shaft is simply screwed into the body of the terminal—in the case of some types the whole terminal, shaft and all, is turned from a solid piece of metal. These terminals slide on vertical brass rods fixed to the back of the screen. Adjustment in a vertical direction is thus provided; while the horizontal rod allows the lamp to be tilted or slid along horizontally. The second figure shows a convenient method of fixing the mirror by a thin sheet brass spring, which allows it to be removed easily for cleaning. The illuminant is a 2- or 4-volt spot-light bulb; there are many different makes of these on the market, and a type should be chosen which has as small a filament as possible, so that the condensing lens may focus the complete filament on the concave galvanometer mirror, in order that a maximum of light may be used. To secure as bright a spot of light as possible, a fairly wide aperture lens should be used, and it is easy to choose one which will give a spot of light easily seen in very slightly subdued daylight, as by

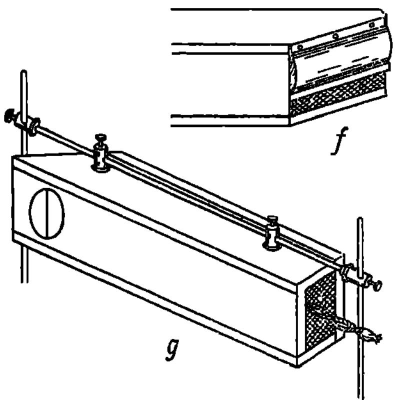


Fig. 140.

simply shading the screen from direct window light. The bulb may be mounted in the ordinary miniature holder on a small block, fitting so as to slide for focusing.

166. LAMP AND SCALE FOR GALVANOMETER

Rev. W. Burton

The lid of a Cerebos salt tin (or a cocoa tin) has a hole punched in it and is placed upside down on a block of wood, which is also bored through. The support of a straight filament electric lamp is screwed on the block above the lid, the leads passing through the block to the town supply. The can has a rather wide slit cut in one side so that the filament can be seen when the can is fitted into the lid. The filament can be focused on a scale attached to the front of the block. The block is supported on the ring of a retort stand, to which it can be firmly fixed by a couple of screws or staples.

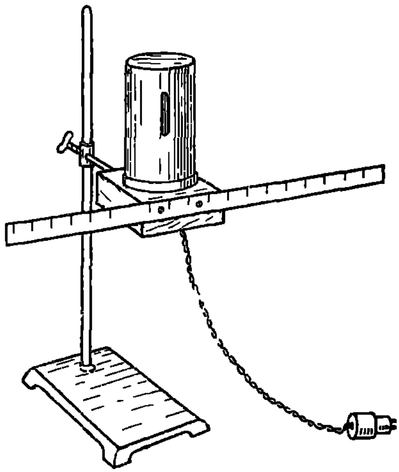


FIG. 141.

MOTOR

167. A MODEL MOTOR MADE OUT OF LABORATORY MATERIALS IN HALF AN HOUR

H. G. F. Micklewright

The armature consists of about 4 yd. of No. 30 D.C.C. copper wire, wound longitudinally on a large cork. The

commutator is made by bending two pieces of thin copper foil round a small cork, the ends of the foil being bent into slits cut in the cork. The bared ends of the armature wire are pushed under the foil. The corks are then

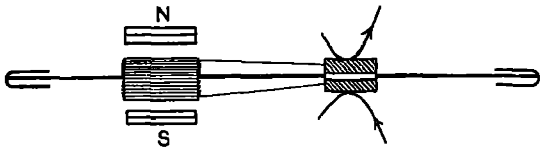


FIG. 142.

mounted on a knitting needle, the ends of which rest against the closed ends of two short pieces of glass tubing. The brushes consist of two pieces of thin copper wire, which are attached to a 4-volt battery, lightly held against the commutator. The field is provided by bar magnets supported above and below the armature; four to six magnets are usually sufficient.

NEON LAMPS

168. THE NEON LAMP

James Taylor

The type of lamp suitable for the following experiments is a familiar commercial article obtainable at a small cost. The lamps comprise two electrodes of iron, enclosed in a bulb filled with neon (containing about 20 per cent. helium and a little hydrogen) at a pressure of about 10 mm. of mercury. The electrodes are of very varied forms, ranging from those with "beehive" or "star-shaped" cathodes, which are used as night lights, to the forms with "letter" cathodes, employed for illuminated signs. The anode in the letter type comprises a short iron rod situated behind the cathode. In the "beehive" type, the anode is an iron disc placed within and at the base of the "beehive."

169. THE NEGATIVE GLOW AND CROOKES' DARK SPACE

James Taylor

A neon lamp, preferably of the " letter " type, operated on a direct current mains supply of 200 volts or more, in an ordinary lamp socket, exhibits some of the important features of the electric discharge in gases. The lamp should be placed in the socket so that the " letter " electrode is illuminated. This is then the cathode of the discharge tube. It is completely covered with an orange-yellow glow, called the " negative glow." If the cathode is examined in section, it will be seen that the cathode glow is separated from the cathode surface by a sharp distinct layer, which is dark relative to the glow. This is the well-known Crookes' Dark Space. Between the negative glow and the anode there is another dark space, the so-called Faraday Dark Space. In some few tubes a faint glow is discernible on the anode or small electrode. This is the " anode glow."

If the lamp is now reversed in its socket, it will be seen that the glow becomes confined to the small electrode, which is now cathode.

170. TO DISTINGUISH BETWEEN DIRECT AND ALTERNATING POTENTIALS

James Taylor

The nature of the lamp lends itself immediately to the distinguishing of the polarity of the terminals of a D.C. supply of the value of about 200 volts or more. If the lamp is connected across the terminals of the supply, the negative terminal is immediately indicated by the fact that the negative glow occurs only on the electrode which is connected to the negative supply terminal. The connections from electrodes to contact lugs may be deter-

mined once and for all on a voltage supply of known polarity.

Further, a neon lamp may be used to find out whether an electric supply is D.C. or A.C. The lamp is connected to the supply ; if there is a glow on both electrodes, then the supply must be alternating current.

171. TO MEASURE THE CURRENT CONSUMPTION OF A NEON LAMP

James Taylor

A milli-ammeter should be placed in one of the leads of the circuit of the neon lamp. It will show a current of about 20 milli-ampères on a D.C. voltage of from 200 to 250. This small current consumption is not primarily a property of the neon tube itself, but is due to a " ballasting " or controlling resistance of some thousands of ohms, concealed in the lamp cap.

172. TO REMOVE THE " BALLASTING " RESISTANCE

James Taylor

The solder of the contact lugs on the lamp cap may be removed by a heated soldering iron, and the lead-in wires freed. The bayonet catches in the brass cap are readily pulled out by small pliers, and the holes enlarged. The brass cap may then be cut off with scissors or torn off by pliers, leaving the ballasting resistance exposed. The resistance is easily removed, and the freed lead-in wires may then be soldered to extra insulated wire leads, or the lamp may be mounted into a brass cap taken from a worn-out electric lamp. The resistance is made of fine resistance wire wound on to a red-fibre strip. If mounted upon a small ebonite base with terminals, it forms a very serviceable resistance for general purposes.

173. THE SPARKING POTENTIAL

James Taylor

The neon tube must now be connected to a direct current source of potential, which may be gradually raised in value (for example, by a rheostat potentiometer on 200 D.C. mains, see Fig. 143, where the voltage from the potentiometer is indicated by E), and a variable resistance of a few hundreds of ohms (one of the sliding contact resistances wound on a porcelain former is suitable). A voltmeter should be connected across the potentiometer to measure the potential applied to the lamp.

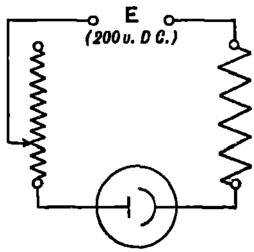


FIG. 143.

When the potential applied to the lamp is gradually increased from a low value, it is found that as soon as the voltage attains a certain critical value, a discharge passes and the lamp begins to glow. This potential at which the discharge is initiated is definite and constant for a given lamp and is called the " sparking potential." The possession of a sparking potential is a property of all forms of discharge tubes.

174. THE EXTINCTION POTENTIAL

James Taylor

If now the voltage across the lamp is gradually diminished, the discharge persists, but the intensity of the glow progressively diminishes, and at a definite potential, usually of the order of 30 volts less than the sparking potential, the discharge abruptly ceases. This " extinction potential " is also a general property of discharge tubes.

175. TO SHOW THAT VERY MINUTE CURRENTS ARE SUFFICIENT TO MAKE NEON GAS GLOW

James Taylor

A neon tube from which the ballasting resistance has been removed is connected in series with a variable high resistance, and a micro-ammeter or other sensitive current measuring instrument to the D.C. mains (voltage greater than 200). The resistance may be formed by a pencil line on ebonite, if other forms are not available, and may be varied by rubbing on more graphite or removing some from the ebonite. An excellent, though somewhat more complicated, high resistance is provided by a wireless three-electrode valve with battery and filament rheostat, the plate and grid terminals being joined. The resistance between the plate-grid terminal and the filament may be varied by variation of the filament heating current, and may be used as a current control for a neon lamp circuit, though it must be pointed out that it is not of the same nature as an ordinary resistance and is not subject to Ohm's Law.

Other suitable resistances are readily available in the form of the high resistances of variable type so familiar to all wireless enthusiasts.

The neon lamp should be shielded from all external illumination, or viewed in a dark room, and the resistance in the circuit be increased progressively until the glow is just visible. It is found that the glow is still visible with a current of only one millionth of an ampère flowing. Indeed, in certain neon discharge tubes, the glow is easily seen at current densities of as little as 10^{-9} amps. per cm^2.

It is evident, then, that there is practically no limit to the smallness of the current which will cause neon gas to glow, but there is a very definite lower limit to the potential across the electrodes which, for very small circuits, cannot be made much less than the sparking potential value, namely, of the order of 160 volts, for a glow discharge to occur.

176. TO STUDY THE NATURE OF THE DISCHARGE AT DIFFERENT CURRENT VALUES

James Taylor

The practical arrangement described in the last experiment may be used for the present purpose. Commencing with the circuit resistance of a very high value (tens of megohms), the glow of the discharge will be seen to be principally on the anode and in its vicinity. This discharge with currents of a few micro-ampères is the " corona " type of discharge, and shows the type obtained before the discharge has built up to large current values.

The current is gradually increased by decreasing the circuit resistance. It will be seen that the maximum of brightness of the discharge increases in thickness and extends towards the cathode. A negative glow is being built up. With further increase of the current, the discharge usually alters discontinuously into a small crescent of negative glow upon the cathode. In this region the discharge usually becomes intermittent with an audio frequency, which can be detected if a pair of earphones is included in the circuit. With further increase of current by decrease of resistance, the discharge assumes the normal form, and the voltage across the tube falls to the " extinction " value, but only a part of the electrode is covered with glow. (The micro-ammeter must, of course, be removed before this point and replaced by a less sensitive instrument, if current records are required.)

As the resistance in the circuit is further reduced, the area of the electrode covered by the glow increases in direct proportion to the increase in the current, but the voltage across the tube remains constant at the " extinction " value.

When all the cathode is covered by negative glow, further reduction of the resistance in the circuit brings about an increase of current through the lamp, and an intensifying of the glow takes place. This is the region

of "abnormal" cathode fall. The voltage across the neon lamp increases as the current increases, and the discharge becomes brighter and still brighter whilst the glass walls of the bulb fluoresce. The electrodes of the lamp are heavily bombarded by the electrons and ions of the discharge, with the result that they heat up. If the supply voltage is high enough, they become red hot. At this point the glow often begins to change from the orange-yellow type of the normal lamp to a bluish colour. The lamp is permanently altered, and hereafter will always require a higher potential to drive it, and the colour of the discharge will be permanently changed.

At these higher currents the violence of the cathodic bombardment produces a spluttering of the metal of the cathode and a consequent deposit of a metallic film on the glass walls and, finally, in the limit an arc is struck across the tube electrodes and the lamp is destroyed.

177. TO ILLUSTRATE THE CURRENT RECTIFYING PROPERTIES OF DISCHARGE TUBES

James Taylor

The current through a discharge tube is normally proportional to the area of the negative glow. Now in most forms of neon lamps, especially those supplied commercially in England, the area of one electrode is considerably less than that of the other, and the lamp exhibits a pronounced unilateral conductivity. Letter lamps which have small anodes are the best type of lamp for illustrating this property. If an alternating source of potential be put across the lamp electrodes in series with a milli-ammeter, the current when the electrode of large area is the negative electrode, is much greater than the current when the electrode of small area is the negative electrode, and partial rectification is obtained, as is shown by the milli-ammeter registering a current.

178. TO MAINTAIN A CONSTANT POTENTIAL BY USE OF A NEON LAMP

James Taylor

It has been shown in a previous experiment that, provided the area of the cathode is not completely filled with negative glow, the voltage across the lamp terminals remains constant. This constant voltage may be utilised for electrostatic experiments, such as charging up a condenser or electrostatic voltmeter. (It cannot, of course, be used for purposes which require more than a minute quantity of energy.) The method can also be used for the subtraction of a constant voltage from a source of high potential.

179. STABILISING THE CONSTANTS OF NEON LAMPS

James Taylor

Neon lamps differ somewhat widely in their properties, and some are not characterised by sufficient stability of their voltage constants to make their application to the measurement of capacities and resistances, as described in following experiments, trustworthy. They may be improved considerably by passing a current greater than that normally taken, for an hour or two, though it is wise to avoid a heavy metallic deposit from the electrodes on the walls of the tube, as easily occurs when tubes are " overrun " in this manner. It is also preferable, when measuring capacities, etc., by the neon lamp, to illuminate the cathode by means of a gas-filled lamp, which produces a small photoelectric effect at the cathode and usually does away with the time lags in production of discharge, which are frequently noticed in the dark. Lamps to be used for demonstrating the photoelectric effects of light and other radiations (see experiment 193) should not, however, be " overrun," for this usually destroys their sensitivity.

The best method of making a tube suitable for exact measurements is by the introduction of a small quantity of sodium into the lamp. (See experiment 183.)

180. SIMPLE METHOD OF ILLUSTRATING THE CHARGING-UP OF A CONDENSER AND OF MEASURING CAPACITIES AND RESISTANCES

James Taylor

It has been shown that the neon tube possesses the property of starting at a definite sparking potential, v_c, and going out at an equally definite extinction voltage, v_b. These facts are, of course, illustrated by the simple experiments described above. The property may be advantageously employed for illustrating the charging-up of a condenser. A source of potential of some 160 or 200 volts is connected by a tapping key and high resistance to the condenser (suitable value of the order of 1 microfarad), which is shunted by the neon lamp. The tapping key is closed, and after a definite interval, a "flash" of the neon tube takes place. This flash, of course, occurs when the capacity has been charged up to v_c volts, and the time taken may be measured by a stop-watch. The time may be shown to vary proportionally to the resistance and capacity values, and if the value of one of these is known, the value of the other may be calculated from the usual formula for the charging up of a capacity.

$T = 2{\cdot}303C \times R \times \log_{10} \dfrac{E}{E - v_c}$, where E is the charging voltage.

181. TO APPLY THE NEON LAMP TO THE MEASUREMENT OF CAPACITIES AND RESISTANCES

James Taylor

A condenser of capacity C (of the order of 0·1 microfarad and upwards) is placed in parallel with a neon tube

(preferably with the ballasting resistance removed) and connected in series with a high resistance R (of the order of 1 megohm) to a D.C. supply of constant voltage (see Fig. 144). Regular flashing or discharge through the lamp at intervals occurs. With a capacity of the order of 1 microfarad, the flashes may be timed by a stop-watch. The time between flashes is found to be constant and is diminished with decrease of the value of the capacity or resistance, until, finally, the periodic clicks, which may be heard if a pair of telephones is included in the circuit, become a low musical note. The pitch of this note increases with further decrease of C or R until, with low values of both C and R, notes beyond the audio limit may be attained.

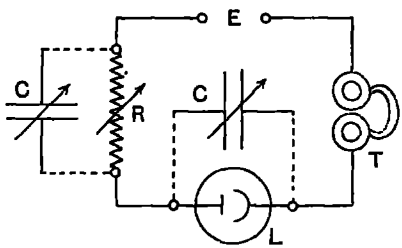


FIG. 144.

The mechanism of flashing is as follows. The condenser C charges up from the source of potential E volts, through the high resistance R, and when it attains the potential v_c, discharge through the lamp occurs. The capacity discharges through the tube, but as soon as the potential has fallen to the extinction value v_b, discharge ceases and the condenser again charges up to v_c, and the cycle is repeated. The time between flashes is thus equal to the time required for the capacity to charge up added to the time required for the capacity to discharge through the tube, and this may be evaluated theoretically, giving

$$T = C \times R \times 2{\cdot}303 \times \log_{10} \frac{E - v_b}{E - v_c} + Ck.$$

k is a small constant, so that the relationship may be approximated to the form—

$$T = C \times R \times \text{Const.}$$

This provides a simple method of capacity measurement.

A similar relation is also obtained when the capacity is placed in parallel with the resistance R, instead of across the lamp, and this position is equally suitable for capacity and resistance measurement, although it is omitted in this description. (The alternative positions of the capacity are shown in Fig. 144.)

If graphs be drawn showing the variation of the time of flash with the capacity (resistance and voltage E constant), or the resistance (capacity and voltage E constant), these are found to be straight lines in accord with the above relations, though the lines do not necessarily pass through the origin.

In practice, a graph showing the relation between the time of flash and the value of the capacity may be constructed by taking the times of flash by means of a stop-watch for two known capacities, and the capacity of a condenser of unknown value may be measured by finding the time of flash with this capacity across the neon lamp and referring to the graph. Alternatively, without constructing a graph, the capacity value may be found by interpolation between two known values. If the lamp has been treated by introduction of sodium (see No. 183), the approximate form of the relation given above usually holds almost exactly. The method for resistance measurement is exactly similar.

182. THE NOTE METHOD OF MEASURING CAPACITIES AND HIGH RESISTANCES

James Taylor

In cases where the rate of flashing is too great for counting, resort can be made to "note" methods, if a variable capacity of the same order or greatness as the unknown can be obtained. The lamp terminals are joined to the middle poles of a double-pole double-throw switch (six-way key), whilst the standard variable capacity is connected to one end pair of terminals and the unknown capacity to the other pair, as shown, so that either the

standard or the unknown may be placed at will across the neon lamp. By throwing over the six-way key rapidly from one position to the other, the difference of note due to the capacities may be detected in the telephones, T. The variable capacity is adjusted in value till the notes in the two positions are the same, when it is obvious that the two capacities must be of the same value.

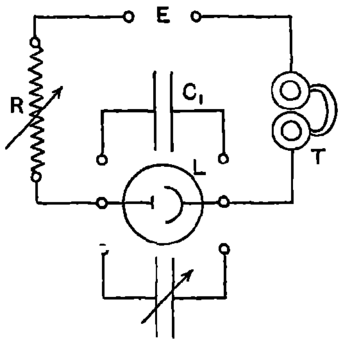


FIG. 145.

A flashing neon lamp is also very suitable for demonstrating the properties of rotating mirrors and stroboscopes, since it provides a bright glow at regular and adjustable time intervals.

183. TO INTRODUCE SODIUM ELECTROLYTICALLY INTO NEON LAMPS AND FILAMENT LAMPS

James Taylor

A neon lamp is placed with the lower part of the bulb in a bath of molten sodium nitrate (see Fig. 146); the lamp should be heated up gradually above the bath before introduction into the nitrate. The bath may be made of aluminium or iron. It is heated to a temperature of about 350° C. by a Bunsen flame. The neon lamp is made to glow on the usual voltage supply, and a voltage of some 100 or more is

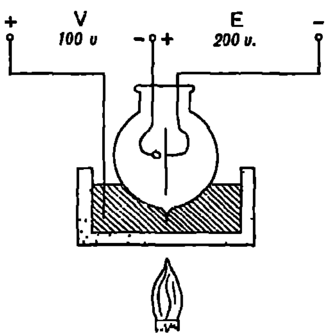


FIG. 146.

connected from the positive electrode to the metal bath, in which the sodium nitrate is contained, in such a way that the metal bath becomes the positive electrode. A discharge will be seen to take place between the glowing electrodes and the part of the bulb which is immersed in sodium nitrate. The action is somewhat as follows. The inside surface of the glass wall is bombarded by ions and electrons from the discharge and becomes negatively charged. The outside glass is positively charged from the potential V and forms the anode. Under the influence of the intense electric field between the two sides of the glass, there is a migration of the positive ions of sodium which are found in quantity in the molten sodium nitrate, and these are driven to the inner surface of the glass, where they are vaporised. After this action has proceeded for an hour or so, a mirror of the metal sodium can be seen on the inner surface of the glass. The sodium metal frequently assumes a colloidal form of a dark brown colour. Further, since most of the neon discharge tubes are made from lead glass, there is usually an action upon the lead after the discharge has taken place for some time, and the glass becomes coloured almost to blackness.

Some of the sodium is, of course, evaporated on to the electrodes, and gives an electrode surface of fresh sodium metal. The introduction of sodium has the effect of lowering the sparking potential by 40 or 50 volts, and increases the stability of the tubes to such a degree that it becomes unnecessary to use external ionising agents in the capacity and resistance experiments.

It is perhaps of use to point out here that sodium may be introduced in an exactly similar manner into an ordinary wire-filament lamp (see R. C. Burt, *Journ. Opt. Soc.*, 11, 87, 1925), using the hot filament instead of the discharge.

184. TO ILLUSTRATE AN ALTERNATIVE METHOD FOR THE INTRODUCTION OF SODIUM INTO A NEON LAMP

James Taylor

A rather more striking method of carrying out the experiment is to short-circuit the two electrodes of the neon lamp, connect them to the negative terminal of a variable source of potential, and connect the bath of molten sodium nitrate to the positive terminal. The adjustable source of potential may be conveniently the D.C. mains connected in series with a battery of about 100 volts (adjustable). In this arrangement, conduction of electricity can occur only through the glass walls of the neon lamp. The voltage is gradually increased from a value about 240 volts until a discharge occurs in the lamp. The potential at which this occurs is usually about 300 volts. The discharge is initially of the normal orange colour, but it soon shows a strong yellow tinge, due to the sodium which is coming through the glass walls.

185. TO PROVE THAT SODIUM IS A CONSTITUENT OF GLASS

James Taylor

A strong yellow discharge is characteristic of sodium, as will be shown in later experiments.

For the present object, the circuit is exactly the same as that described in the last experiment, but in place of a bath of sodium nitrate, one of heated mercury is used. A heat-resisting glass or iron container must be used for the mercury. The voltage is gradually increased, as in the last experiment, until a glow discharge strikes at about 300 volts. The discharge is at first orange in colour, but soon becomes strongly tinged with the yellow colour characteristic of sodium. Since mercury contains no sodium, the sodium must have come from the glass

walls of the lamp. Simply speaking, we may regard glass as sodium silicate, Na_2SiO_3. Under the influence of the electric potential between the mercury and the inside of the neon lamp, electrolysis of the Na_2SiO_3 occurs in the manner—

$$Na_2SiO_3 \rightarrow 2Na \quad (SiO_3)^{=}$$

The positive sodium ions migrate to the negative electrode, which is the inside of the discharge bulb, and are liberated there. The glass walls of the tube are thus electrolysed and finally broken down, and sodium is introduced into the lamp.

186. TO ILLUSTRATE THE REVERSIBILITY OF THE ELECTROLYTIC DISCHARGE

James Taylor

After sodium has been introduced into a neon lamp as described in experiment 183, the polarity of the terminals is reversed, that is, the sodium bath is made negative instead of positive. It is then found that a glow discharge still occurs, but that the inner surface of the glass bulb is acting as cathode and is covered with negative glow. The electrolytic discharge is consequently reversible, and sodium may actually be removed from the inside of the lamp and driven through the glass walls to the outer side. This experiment illustrates very strikingly the conduction of electricity through glass, for it is evident that the glass which is covered with a normal negative glow is behaving in a manner analogous to a metal cathode.

The current passing through the walls of the lamp when used on reverse discharge is initially large, but falls off exponentially with time, due to polarisation effects in the glass. Rotation of the discharge on the glass surface and fatigue effects are very evident with this type of discharge.

187. THE LAMP AS A SOURCE OF LINE SPECTRA

James Taylor

The negative glow of the neon lamp, especially that of the " letter-form " pattern, may be utilised as a source of line spectra rich in lines. The lamp is a good substitute for the more expensive forms of discharge tube. The glow should be examined sideways in order to obtain maximum intensity.

A constant deviation spectrometer is a very suitable instrument for measuring the wave-lengths of the spectral lines from the tube. It is only necessary to set up the lamp close to the slit of the spectrograph. The lines are numerous and mainly confined to the red and yellow portions of the spectra. The spectra of neon and helium occur, and the lines may be measured and compared with the values given in an atlas of spectra. The Balmer Series of hydrogen is also strongly in evidence, for the lamps contain about 1 per cent. of hydrogen, which is introduced in order to obtain a low sparking potential. The yellow sodium lines are almost always to be seen, indicating the universal presence of this element. In the ordinary lamps, which have not been used for drastic experimental purposes, no band spectra are present.

As a matter of interest, the variation of the intensity of the lines with the current through the lamp may be studied.

188. TO SHOW THAT THE YELLOW GLOW DISCHARGE IS DUE TO SODIUM

James Taylor

The neon lamp is set up as in experiment 183 for the electrolytic introduction of sodium, and the discharge is examined by the spectroscope. As soon as a discharge is passed, the sodium lines become more prominent. When the discharge becomes yellow, examination shows

that this yellow discharge gives principally the yellow sodium lines, proving that it is due to sodium.

189. TO PROVE THAT HYDROGEN MAY BE REMOVED FROM THE NEON LAMP BY THE ELECTROLYTIC DISCHARGE

James Taylor

The experimental arrangement used for experiment 186 is employed, and the glow discharge on the surface of the glass bulb is examined by the spectrograph. At the beginning of the discharge, the Balmer lines of hydrogen are found to be prominent. After five minutes' run, only a faint trace of the hydrogen lines can be observed in the lamp spectrum. With continued running, the hydrogen lines disappear completely. The hydrogen has evidently been removed from the lamp.

The mechanism is as follows. Under the action of the voltage across the glass walls, the sodium silicate, Na_2SiO_3, is electrolysed. Sodium ions migrate to the outside walls, $SiO_3^=$ radicles are left at the inner walls and break down. The $SiO_3^=$ radicles break down into $SiO_2^=$ silica, and oxygen. A badly conducting layer of silica is formed at the inside surface of the glass bulb, and the liberated oxygen unites with the hydrogen in the lamp and forms water, which is absorbed into the walls and electrodes of the lamp.

190. TO EXHIBIT THE RESONANCE RADIATION OF PURE NEON

James Taylor

The lamp of the previous experiment, when the hydrogen lines have just completely disappeared, is removed from the nitrate bath and rested. After resting, the discharge through the lamp is examined. A noticeable change in the type of discharge is observed. The cathode is still covered with orange negative glow, but,

in addition, it is bathed or surrounded in a red luminosity which almost fills the bulb. This diffuse red glow is resonance radiation of neon, and it is observed only when the gas is free from impurities (a small admixture of helium is, however, without influence). The red mantle is, in fact, resonance light called up by absorption of light from the negative glow in the cloud of abnormal neon atoms (excited metastable atoms) which surrounds it. The abnormal neon atoms absorb radiation from the discharge and then re-emit it with a changed wave-length as a visible red light. This experiment illustrates the fact that excited atoms can absorb radiation of suitable wave-length and then revert into normal atoms with emission of light.

191. TO SHOW THAT THERE ARE COMPOUNDS OF CARBON IN THE GLASS WALLS OF THE TUBE

James Taylor

Instead of discontinuing the discharge when the hydrogen lines have disappeared, as was done in experiment 189, the discharge may be continued. After a prolonged run, a band spectrum begins to appear and increases in strength with continuation of the discharge. Measurement of the bands shows that they belong to the carbon monoxide spectrum. The oxides of carbon must have come from the glass walls of the lamp by electrolytic decomposition ; consequently, there must be some compounds of carbon in the glass.

When oxides of carbon have been introduced into the lamps in this way, the discharge shows a bluish tinge and the resonance radiation disappears entirely. At the same time, the sparking potential is found to have increased in value. In cases where the carbon monoxide bands are prominent, a bluish positive glow or column may be observed on the anode.

Voltages of about 350 to 400 are required for the

above experiments with lamps containing oxides of carbon.

The carbonic oxides may be removed from the lamp if the polarity is reversed and sodium is introduced into the lamp. The sodium fixes some of the oxides by chemical action, whilst some disappear into the glass by taking part in electrolysis.

192. PRODUCTION OF ELECTRICITY BY FRICTION AND THE ELECTRODELESS DISCHARGE

James Taylor

Neon is extremely sensitive to electrical influences and glows very readily in electrostatic fields which are varying in intensity. It is consequently possible to demonstrate the charging-up of a glass surface by means of the neon lamp. The tube is simply held in the hand without any electrical connection whatever being made, and the glass walls of the tubes are briskly rubbed with the hand (which must be extremely dry), or better still, by a rubber glove. If the process is carried out in a dark room, it will be seen that the gas in the lamp glows diffusely but brightly, following the progress of the rubber across the glass. Indeed, it is not necessary that there be electrodes within the tube, for a simple bulb of neon acts in an exactly similar manner. The glow obtained is of a red colour characteristic of neon.

As a variation of this experiment, a gas-filled lamp (broken filament does not affect the experiment) may be utilised to the same end. Many gas-filled lamps contain argon, or rather a mixture of argon and nitrogen, so that the glow obtained in this case is of a blue colour, characteristic of the above gas. Discharges of this nature, which are produced by a varying electric field without the intervention of electrodes, are termed electrodeless discharges.

In an analogous manner, the neon lamp may be utilised to illustrate the energy leakage from a working induction

coil. The induction coil radiates energy into the space around it and creates a varying electric field, which is detected by the tube if it is held sufficiently near. In this manner it may be shown that the radiation from a large induction coil extends to some considerable distance.

Neon lamps may also be employed to advantage in experiments with Lécher wires, or with the Fleming cymometer.

193. PHOTO-ELECTRIC AND RADIATION EFFECTS

James Taylor

The fact has frequently been observed that the conditions under which a neon lamp begins to discharge vary with the conditions of illumination, etc. It has also been found that the flashing phenomena of such tubes may (to a certain extent) be controlled by radiation falling upon the electrodes. Thus, if the voltage applied to a neon lamp is adjusted to be precisely of the sparking potential value, then no discharge will occur if the lamp is in darkness, but if an electric lamp is illuminated in the vicinity, or if a beam of radiation, such as light, or radiation from radioactive substances, X-rays, etc., though of small intensity, is allowed to fall upon the cathode, a discharge will be initiated and will continue even though the radiation is suppressed. This phenomenon may be utilised for the remote control of relays and instruments by light and other radiations.

194. CONTROL OF FLASHING BY RADIATION

James Taylor

In the control of flashing by radiation, the circuit used is shown in Fig. 144, p. 207. E is an adjustable supply of voltage (about 150 to 200 volts), R a variable resistance of the type described previously, L the neon lamp, and C a condenser. In the case of the " Osglim " lamps, suitable values of R and C are about 0·3 megohm and 1

microfarad. The potential of E is adjusted so that flashing just fails to take place in the dark. Now, if radiation, even from a distant source, is allowed to irradiate the cathode, flashing occurs, and the rate of flashing varies with the intensity of the radiation. The system is self-restoring, or, in other words, the flashing ceases so soon as the stimulating influence of the radiation is suppressed. It should be mentioned here that this radiation effect is a phenomenon of less constancy and reliability than most of the other properties of the neon lamp, and, indeed, all lamps do not exhibit this effect. Nevertheless, it is well worth the trouble to try to find a lamp which exhibits this very striking and demonstrable phenomenon. One is most likely to succeed with a lamp of the " letter " form, having a small anode. The " letter " or large anode is connected to the negative terminal of the supply.

OHM'S LAW

195. VERIFICATION OF OHM'S LAW

H. A. Wootton

One Leclanché cell is used, and the rheostat is adjusted until there is no deflection in the sensitive galvanometer. The terminal potential difference of the resistance is then equal to the electromotive force of one Leclanché cell. The current passing through the resistance can then be read off on the ammeter.

Two Leclanché cells are now put in, and the experiment is repeated. The current has now been increased so that the terminal potential difference of the resistance is equal to the electromotive force of two Leclanché cells.

The experiment can be repeated with any number of Leclanché cells which may be available, and the relation between the current passing through the resistance and the terminal potential difference determined.

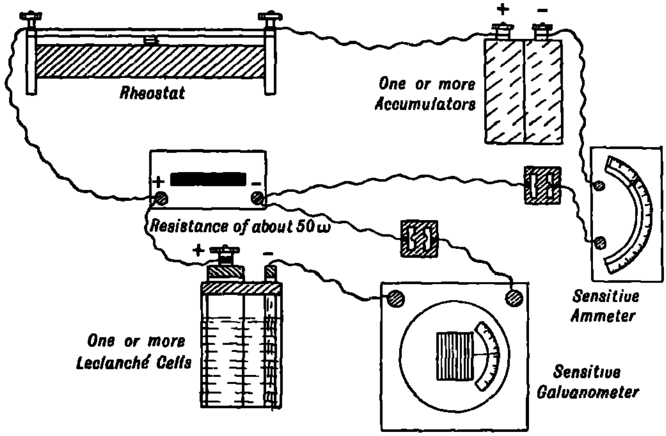


FIG. 147.

The following results, obtained by a boy working without special supervision, show the accuracy that can be expected :

Number of Cells.	Current.	$\frac{\text{Number of Cells.}}{\text{Current.}}$
1	0·294 ampère	3·4
2	0·58 ,,	3·45
3	0·87 ,,	3·45
4	1·15 ,,	3·46
5	1·46 ,,	3·43

OSCILLATOR

196. USE OF THE OSCILLATOR IN ELECTRICAL EXPERIMENTS

S. R. Humby

The apparatus of experiment No. 96, p. 109, has a wide range of usefulness in electrical experiments, as well as in sound. Two uses in electrical work may be of interest.

(1) Capacities of condensers can be found in terms of that of the variable condenser, or of some other standard, by a method of substitution.

(2) The apparatus gives a convenient supply of alter-

nating current for conductivity measurements. It is best to insert a step-down transformer (a cheap one can be bought from a wireless dealer) between the oscillator circuit and the Wheatstone bridge circuit. The high impedance winding of the transformer replaces the telephone of Fig. 89, p. 109, and the low impedance winding is connected across the ratio arms of the bridge in the usual manner. The apparatus needs no attention and makes no sound in the laboratory—a great advantage over the small induction coil which is so often used during the determination of the resistance of electrolytes.

POTENTIOMETER

197. DIRECT READING POTENTIOMETER

S.S.R., (VI) 22

This was made as a laboratory model to explain the working of the commercial direct-reading type of instrument. It consists of a potentiometer wire in series with a continuously variable resistance. The circuit, when connected up for use, is as below.

The method of use is as follows : AB is the calibrated potentiometer wire, BC the variable resistance. For use,

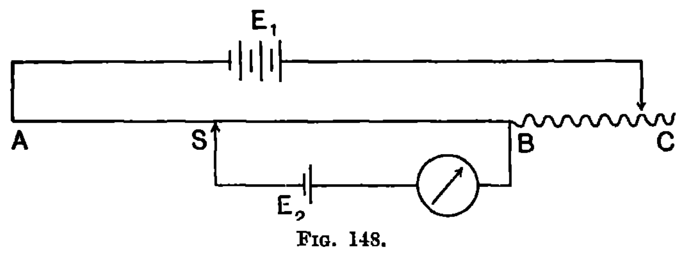


FIG. 148.

a battery giving 4 or 6 volts is connected at E_1 and the standard cell at E_2. The battery E_1 should be an accumulator, but must in any case be capable of giving a steady current without drop in external P.D. To set the instrument for use, the slider is set to the reading corresponding

to the E.M.F. of the standard, and the potential balanced by adjusting the resistance, BC. When this has been done, the drop in potential from B to S will be equal to the slider reading, so that the scale on AB will read directly in volts so long as the E.M.F. and resistance of E_1 remain constant and the resistance, BC, is not altered. The standard is then removed and the cells to be tested inserted at E_2, the E.M.F. being balanced by adjusting the slider, S, without altering the resistance, BC.

This actual instrument consists of a nickel-chrome wire, 30 in. long for AB and about 50 in. for BC. The scale on AB reads to 3 volts, 10 in. representing 1 volt.

RESISTANCE

198. HIGH RESISTANCE

Birmingham, 1931

Several strips of paper, well rubbed with graphite, are held by binding screws on the under side of a shallow wooden box lid. The resistance is easily adjusted to any desired value, say 5,000 ohms, by removal or addition of a few strips. This is useful as a block resistance, but is liable to variation due to damp, but this can be reduced if the box lid is screwed down and the whole then well painted with shellac.

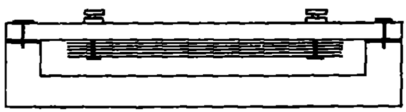


FIG. 149.

199. A WHEATSTONE BRIDGE FOR USE IN EXPERIMENTS ON THE VARIATION OF RESISTANCE WITH TEMPERATURE

S. R. Humby

The circuit is of the standard type and the apparatus is made up so as to use resistances already available in the laboratory.

The points BB are, of course, for connection to the battery, and the 50-ohm resistance is not essential. The

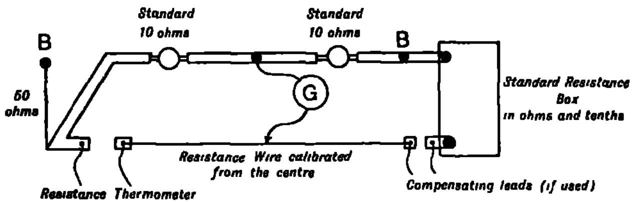


FIG. 150.

arrangement can be made more or less sensitive according as the resistance of the actual bridge wire is low or high.

The platinum resistance thermometer can also be made in the laboratory with a hard glass outer tube, so that its construction is visible.

WIRELESS

200. TO DEMONSTRATE THE OCCURRENCE OF ELECTROMAGNETIC OSCILLATIONS

C. L. Reynolds

The components described below can be varied within a wide range: the best conditions for any particular apparatus can be found by trial.

Condenser.—A Mansbridge type, or preferably a mica condenser of anything from 0·1 to 2 microfarads, may be used. It is convenient to have one of variable capacity, or at any rate two similar condensers in series, one of which can be short-circuited.

Inductance.—This should be of the order of 0·1 henry, and, if possible, in two parts, one of which can be short-circuited. The field coils from a series motor are suitable, but the coils of a low resistance electromagnet will serve. In any case, the resistance must not be more than a few ohms. If need be, the inductance can be increased by inserting an iron core, preferably laminated, and varied

by clamping an iron keeper near, but not in contact with, the poles of the core.

Telephone.—Headphones or a loud speaker will serve

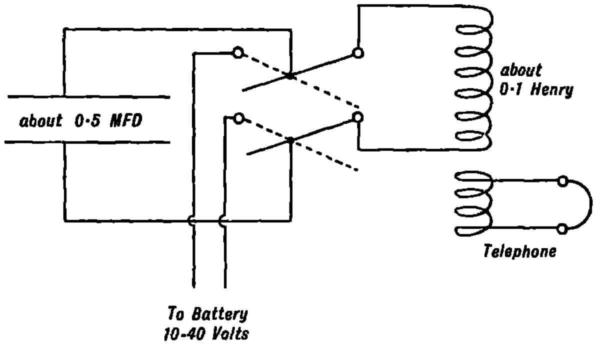
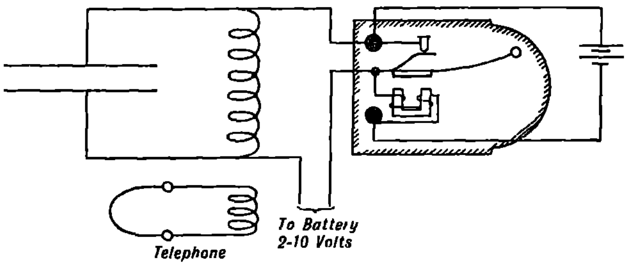


FIG. 151.

If a low-resistance instrument is used, it must be coupled inductively to the inductance, as in the figure. A high-resistance receiver may be connected to the ends of the inductance.

Method of Procedure.—1. Connect as in figure. With the two-way switch first charge the condenser from a battery and then discharge through an inductance.



2 (*Alternative Method*).—To the ends of the inductance connect (*a*) the condenser, (*b*) the telephone and (*c*) a Leclanché or a single storage cell with a silent knife-switch. Break the switch quickly (to avoid an arc), thus

charging the condenser by means of the magnetic energy in the inductance.

In either case, oscillations are set up; they are rapidly damped, but the telephones give a sound like that caused by plucking a tennis-racquet string. The pitch can be varied by altering either the inductance or the capacity.

By arranging a mechanical make-and-break to repeat the experiment some twenty times per second, a steady note is produced in the telephones which is audible all over the classroom. (An ordinary trembler bell will serve, if nothing better is available—Fig. 152.)

201. DISCONTINUOUS WAVE TRANSMISSION AND RECEPTION

C. L. Reynolds

A simple transmitting set is easily made from a small induction coil, a Leyden jar, a home-made spark gap

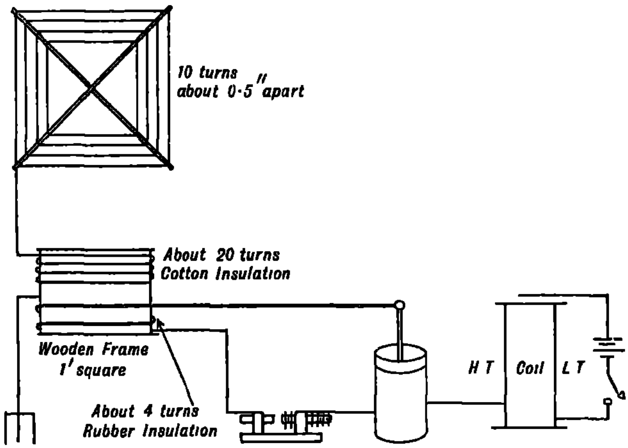


FIG. 153.

(about ⅛ in. across, with flat faces), and a loop aerial about 2 ft. square (Fig. 153). It is more satisfactory to couple the coil to the aerial inductively rather than direct; with

careful tuning it is then possible, by bringing the finger near, to get ½-in. sparks from the aerial.

A Geissler or other tube containing rarefied gas will glow if in the neighbourhood of the aerial. This is a convincing way of showing that there is an E.M.F. in space, right away from wires. It also brings it home that something else is being radiated besides magnetic energy.

A simple receiving set consists of a similar aerial, connected to an air condenser. If a thermo-junction (e.g. iron and platinoid) is available, it can be placed in the circuit and will give a good deflection on a sensitive galvanometer, but only if fairly sharp tuning is effected by adjusting either capacity or inductance. The latter is changed by moving the adjustable clip.

With the use of a crystal or valve (Fig. 154) as rectifier, the

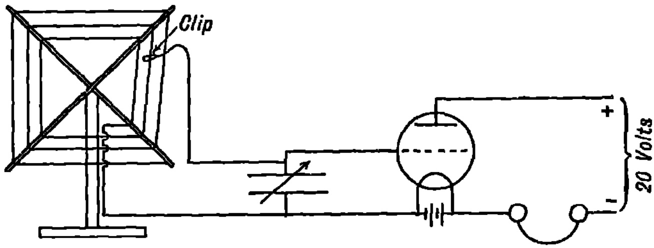


FIG. 154.

circuit may be made to work either a galvanometer or a telephone. In the latter case, very clear messages, with sharp tuning by inductance or capacity, can be sent across a room.

This apparatus will also show the principle of directional wireless. If the aerials are rotated, the message is much the loudest when both are in the same plane; the effect depends mainly on the receiving aerial.

202. TO ILLUSTRATE THE PRINCIPLE OF REACTION

C. L. Reynolds

Connect in series a microphone, the low resistance primary of a transformer and a battery. To the secondary

connect a telephone receiver. Turn the receiver towards the microphone. The small sound oscillations caused by stray noises will be magnified and prolonged by this device, and the receiver emits a continuous raucous noise.

If the transformer of an ordinary field telephone transmitter is used, about 8 volts are required in the primary circuit.

203. TO PRODUCE CONTINUOUS OSCILLATIONS OF AUDIBLE FREQUENCY

C. L. Reynolds

Continuous oscillations of audible frequency can easily be produced by a simple reaction-coil apparatus, using a hard valve (Fig. 155). A convenient form of coupled inductance is provided by a telephone transformer, or

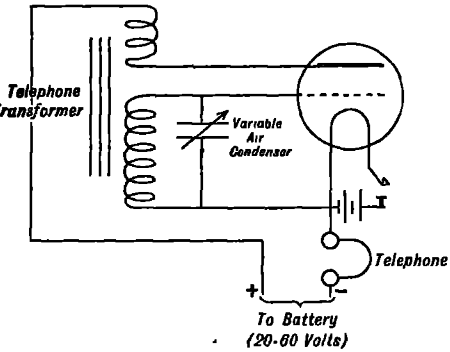


FIG. 155.

failing that, by the primary and secondary of a small induction coil. An ordinary variable air condenser will suffice. The sound produced is loud enough to be heard all over the room when the telephones are on the table; if they are on the ears the effect is stunning. When large cells are used to heat the filament, the note is very pure and steady, and for an illustration of heterodyne reception, it is very convenient to produce sound beats by means of two circuits of this type.

With the telephones removed and a loop aerial substituted for them, the apparatus of Fig. 155 acts as a transmitter, and though the effect is rather weak when an ordinary receiving valve is used for transmission, a simple receiving circuit as in Fig. 154, if properly tuned, will pick up the C.W.

The function of the valve in the receiving circuit is in this case purely to amplify, and the insertion of a suitable number of cells between its grid and the condenser will often make a vast difference in the results obtained. Their number must be obtained by trial, or from the characteristic curve of the valve.

UNCLASSIFIED APPARATUS

204. A SCHOOL-MADE EPISCOPE

H. Armstrong

The following notes concern an instrument made in school at relatively small cost from ordinary materials.

The principles of episcopic projection may be taken as common knowledge. In practice, the problems of construction resolve themselves into securing (*a*) adequate illumination and (*b*) effective ventilation.

Fig. 156 shows a plan, Fig. 157 a cross-section, Fig. 158 a rough general view. The rectangular body is 12 in. high, 24 in. across and 12 in. deep. The base-board projects 10 in., carrying the focusing rack. Light from two projector lamps, A, passes through condensers, B, to trap-door, C, on which the object to be projected is placed. Light from C is focused by lens D being laterally inverted, if need be, by a plane mirror, E. Two switches are shown at F. The lengths of flex are kept in boxes, G, when not in use. Lens D is mounted in wood and can be moved along a rack, J. A hood of black velvet, K, of double thickness, stretches from lens holder to the body of the instrument, being supported by two lengths of spring. It is pinned down closely, but allows free movement of the

projector lens for focusing. The condenser lenses are of diameter $4\frac{1}{4}$ in. They are mounted in wood, covered with asbestos. Lens D is of ordinary laboratory quality, having a diameter of 75 mm. and focal length of 40 cm.

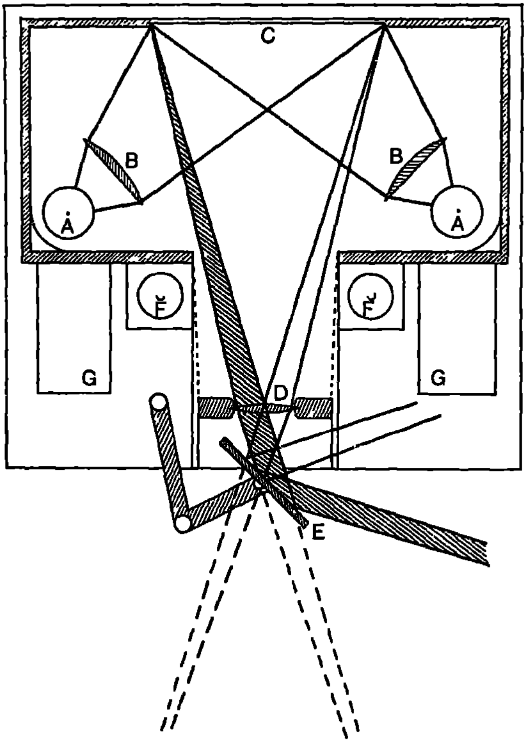


Fig. 156.

The trap-door is $12 \times 9\frac{1}{2}$ in., and horizontal grooves carry a loading plate, $11 \times 7\frac{1}{2}$ in., on which objects are mounted by elastic bands. Lights, condensers, trap-door and projector lens are centred at a height of $6\frac{1}{2}$ in.

The heating is considerable. The wood case of the instrument is lined with asbestos and, further, with sheet tin. The bright metal surface rounded behind the lamps helps to increase the effective candle power. The in-

elegant chimneys were adopted after several indirect methods had been tried. The air enters by holes drilled

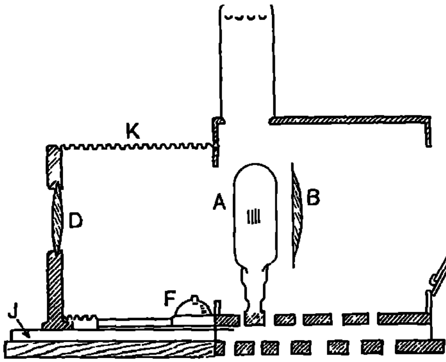


FIG. 157.

in the base-board and in the raised floor. The two sets of holes do not correspond, so that the light finds no direct

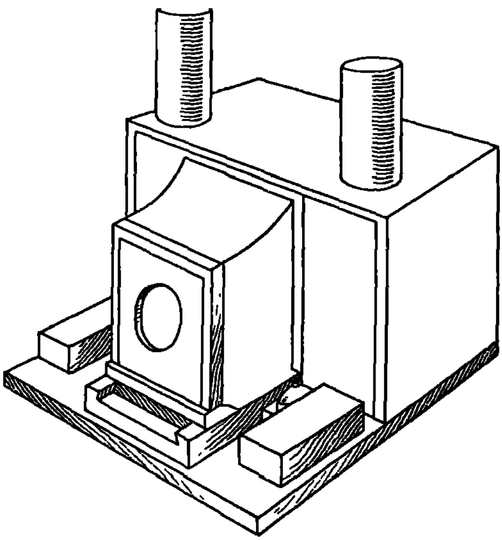


FIG. 158.

exit. The inside of the back wall, including trap-door, is blacked.

The lamps are both 500-watt projector type, burning vertically cap down in screw holders (E.S.); they represent the chief item of cost (25*s*. each). Their life is limited and very much shortened by inadequate ventilation. They must be used in the position specified by the makers, and screwed well down to avoid arcing at the fusible cap. There are types available for burning through a limited range of angle. In cases where a power point is not available, it may be noted that, according to wiring regulations, " a lamp-holder adaptor shall not be used with any appliance taking more than 2 amps."[1] Also, the maximum currents permissible for 14/36, 23/36 and 40/36 flex are 1·8, 3·0 and 5·0 amps. respectively. Thus, if two 500-watt lamps are used in parallel on a 250-volt circuit, then 40/36 flex would carry the 4 amps. with a safety margin. The initial rush of current when the lamps are switched on may be an overload in certain cases. Apart from the question of current, the lower voltage lamps are preferable on account of their more stable filaments.

Unlike the optical lantern, with its standard slide, the episcope projects objects varying in size up to that of the loading plate. Thus the choice of screen size and distance, together with focal length of projector lens, would appear to be a matter of compromise and experiment. In addition to pictures, small objects may be mounted on the loading plate. Images of objects on the floor of the instrument have been thrown on the screen: this led to the trial of small-scale experiments, but this field is extremely limited, owing to lack of focusing depth. Articles, such as flowers and fabrics, placed on the plate, are secured by a piece of glass.

The construction of the instrument represents the collective effort of certain interested boys, who gave freely of their time, energy and ideas.

[1] I.E.E. Regulations are obtainable, 1*s*. 2*d*. post free, from Savoy Place, Victoria Embankment, London, W.C.2, on application to the Secretary.

205. A PROJECTION MICROSCOPE

E. H. Duckworth

By the construction of the simple fittings to be described, it is possible to convert an ordinary microscope into a form suitable for micro-projection, so that a greatly magnified image of an object can be shown on a screen and demonstrated to a large class at once.

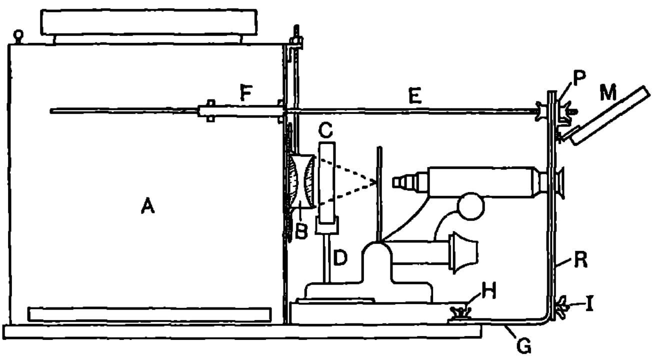


FIG. 159.

The essentials are (see Fig. 159):

(1) A light-trapped ventilated body, A, to house the illuminant.

(2) A condenser, B, to concentrate an intense light on the object.

(3) The illuminant.

(4) A water tank, C, to prevent injury by heat to the lens system of the microscope.

(5) The microscope arranged horizontally.

(6) Arrangements to cut out stray light, consisting of two rods, E, with their supports, G, to carry black velveteen curtains, and in front, with opening for the eye-piece, a thin board, R.

(7) A mirror, M, capable of being turned on a hinge, so that the image can, if required, be projected on to a notebook and accurate drawings made by tracing.

Constructional details will be given in the above order.

The Lamp Body.—An easy and neat method of constructing a lamp body is to build up a rectangular framework from $12\frac{1}{2}$-in. Meccano angle girders ; this may then be boxed in with pieces of thin sheet metal, suitably drilled and fitted with small nuts and screws on the inside of the girder framework. For the sides, thin tin plate is convenient to use ; if this is cut a little short, the holes in the bottom strip of angle girder are left exposed and provide for ventilation.

For covering in the top and condenser end of the framework, an excellent material to use, both as regards ease of working and dissipation of heat, is corrugated sheet aluminium, as used for covering the step-boards of motor cars, and to be obtained from most body builders.

To form a light-trapped chimney, the top sheet has a rectangular hole cut in it, the edges turned up and completed with a cowl and baffle plate, both made of sheet metal, and held in position with Meccano angle brackets. (See Fig. 160.)

The condenser end of the framework is closed in with a piece of the sheet aluminium, but before being fixed in position, has a hole 4 in. in diameter cut in it with a pair of snips (dotted circle, Fig. 161). The centre of this opening should be on the optical axis of the microscope.

The end of the framework distant from the condenser should be strengthened with small triangular slips of metal fitted in the corners. This end may be closed in by a black velveteen curtain, hung from a rod fixed on to the roof of the lantern body.

The ventilation air holes at the sides may be made quite light-tight by covering with aluminium or brass motor-car step-board beading (Fig. 160). The building up of the body requires a large number of small nuts and screws. The most economical way of obtaining these

is to purchase from an ironmonger a gross packet of round-headed metal thread screws and pressed nuts, $\frac{3}{8}$ in. long and $\frac{1}{8}$ in. in diameter. These fit the Meccano girders.

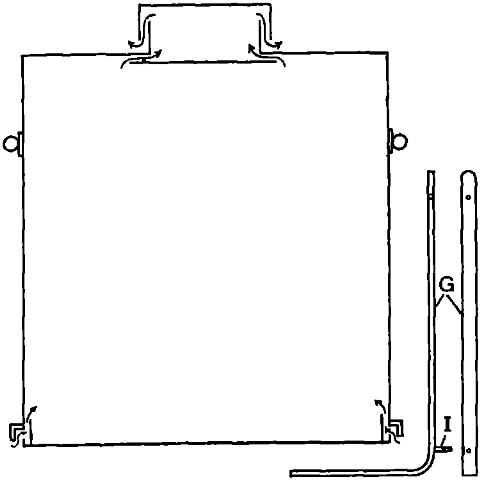


Fig. 160. Fig. 162.

The Condenser.—This is a $2\frac{1}{2}$-in. diameter plano-convex condenser, fitted in a mount as used for portable cinematograph projectors and small lanterns. It can be obtained for a few shillings from Cinema Traders, Ltd., 26 Church Street, W.1.

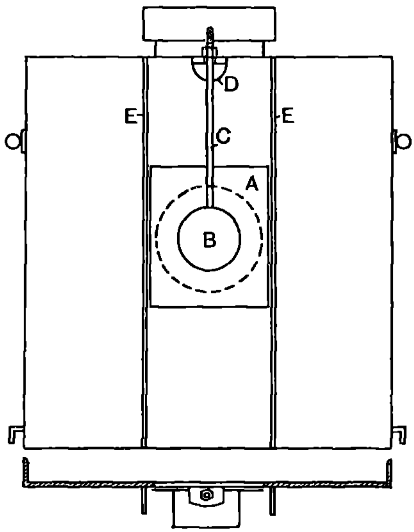


Fig. 161.

The light-tight lamp body is often useful for general optical work, and it is a great convenience to have the condenser quickly removable and adjustable as regards height of optical centre above the base-board. This is attained by drilling holes in the condenser mount and fixing

it with three Meccano angle brackets to a metal plate, A, Fig. 161, with a hole cut in it equal to the diameter of the lens. The plate is arranged to slide up and down between two lengths of Meccano girder, E. The rod, C, which is threaded and fitted with a nut, passes through the bracket, D, projecting from the lamp body. In this way the plate can be fixed in any particular position.

The Illuminant.—This is all-important. The smaller but more intense the source of light the better.

A 10-amp. Triumph "Focuslite" lamp, No. 2c, has been found useful by the writer. Such a lamp will project an image of, say, a stained section of a plant stem to a distance of 5 ft., giving a field of about 18 in.

This lamp is of the concentrated filament type, and once adjusted in correct position in the lamp body, requires no further attention. It is a slight advantage to turn the lamp-holder so that the coils of the filament are in echelon with reference to the condenser. For lecture work to a class of twenty, a 10-amp. Westminster enclosed arc-lamp with carbons at a right angle has been found satisfactory. The area illuminated by light from the condenser is very small, so that arc-lamps on alternating current are liable to give a little trouble by "wandering" and causing the spot of light to move off the object. If continuous current is available, a "Pointolite" lamp might be used.

The Water Tank.—This contains cold boiled water. Suitable small tanks can be obtained from dealers or made for a few pence. (See *Laboratory Arts*, by Woollatt (Longmans, Green).) The tank can be held in a clip (D, Fig. 159) or other convenient support.

The Microscope.—Use the best microscope available, although any medium-quality instrument will give quite good results. The apparatus has been successfully employed for demonstrating rock sections with polarised light to a class of twenty.

In Fig. 159, the microscope and water tank are shown arranged on a separate base-board, but this is not neces-

sary. Once the correct position of the microscope on the base-board has been found by trial, it can be registered with small blocks of wood and subsequent adjustment troubles avoided.

Arrangements to cut out Stray Light.—Two $\frac{1}{4}$-in. diameter iron or brass rods (E, Fig. 159), as straight as possible, are arranged to slide through two tube fittings, F, fastened to the sides of the lamp body.

These tube fittings are easily built up from strip brass and "brass" curtain-rod by soldering together with Britinol soldering paste. Put the parts to be soldered togèther on a piece of sheet asbestos. Add paste to the joints, and heat with a Bunsen burner. The rods that slide through these tubes are threaded at the eye-piece end. They fit through holes drilled in pieces of $\frac{1}{2} \times \frac{1}{8}$-in. iron strip, G, bent to a right angle (Figs. 159 and 162). Two studs (H, Fig. 159), are fixed in the base-board. The iron strips, G, are drilled and fit over these studs, being secured with brass nuts.

A piece of strip or angle brass (P, Fig. 159) is drilled with two holes. This links together the rods, E, and on tightening up the nuts, the framework becomes rigid.

Small screwed studs, I (Figs. 159 and 162), are fixed in the strips, G; over these studs is slipped a sheet of three-ply wood, with a hole cut in it for the eye-piece of the microscope.

Over the rods, and hanging down on either side, are arranged two black velveteen curtains. These, with the board in front, prevent stray light reaching the screen, but enable the microscope to be manipulated.

The Mirror.—When using very high powers or for drawing, it is a great convenience to project the image on to a sheet of paper or a note-book placed on a table below the eye-piece. A piece of good thin mirror is suitable for this purpose. It can be cut to fit in a $\frac{1}{4}$-plate metal dark slide. This is easily fitted with a hinge, and supported from the horizontal brass strip (P, Fig. 159).

The entire removal of the microscope is a matter of

only a few minutes, and the arrangement of the condenser enables other lens systems to be quickly attached, and fittings put in front of the light-trapped lamp body for the projection of a spectrum, horizontal and vertical slide projection, the illumination of a smoke box, or ultra-violet light demonstrations with a window of Chance's filter glass.

The whole apparatus can be given a finished appearance by painting over with a matt, heat-resisting black enamel. Roscoe Cylinder Black, made by Owen Bros. & Co., Ltd., Hull, has been found suitable.

It may be of use to observe that a Meccano axle will just take a $\frac{3}{16}$-in. Whitworth thread. It can be used in some parts of the apparatus : $\frac{1}{4}$-in. Whitworth round brass nuts with milled edge, or fly nuts, can be obtained from George Adams, High Holborn, W.C.1.

206. PHOTOMICROGRAPHY

W. H. Barrett

The apparatus required is simple, and the component parts can all be found in most laboratories. The essentials are illustrated in the diagram, and consist of a

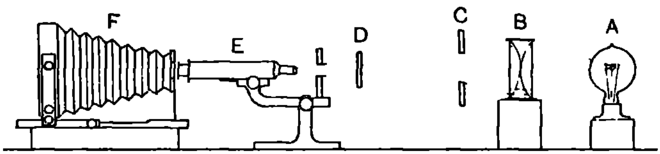


FIG. 163.

source of light, A, a lantern condenser, B, a microscope, E, and a camera, F, without a lens. The best source of light among those tried was a 100-c.p. " Pointolite " lamp. To take a photograph, the positions of the " Pointolite " and condenser are so adjusted as to throw a sharp image of the glowing tungsten ball on the slide in position on the microscope table. Then, by using the focusing screw of the microscope, the enlarged image of the object on the

slide is sharply focused on the ground-glass screen of the camera. At this stage, further small adjustment of the "Pointolite" and condenser may be necessary to obtain even illumination of the field on the ground-glass screen. A circular diaphragm, C, which may be cut out of cardboard and blackened, will be of assistance in cutting down the beam of light from the condenser; while a piece of cloth (clean duster), covering E and F, keeps extraneous light out of the camera. For a simple arrangement of apparatus of this type, only low-power objectives are suitable, greater magnification being obtainable by increasing the distance of the plate from the microscope. (If the apparatus were set up in a dark room and the source of light contained in a light-tight box, the camera might be dispensed with.) Since no microscopic objective is really achromatic, much better definition is obtained by interposing a colour screen between the condenser and the microscope, as shown at D in the figure. A green screen is most generally suitable for this purpose, but for stained or coloured preparations, the choice of colour screens must naturally depend on the colour of the object. When the object is sharply focused on the ground-glass screen, and the illumination is even over the whole field (this is the most important point of all), the light is interrupted, by placing a piece of black card between the lamp and the microscope, and a plate fixed in the camera. The exposure is then made by withdrawing the card for the required period of time.

207. METHODS OF MAKING RELIEF MODELS

W. H. Barrett

There are two methods of making relief models with some approach to accuracy.

For the first of these methods, a map is prepared of the area to be shown in relief, of exactly the same size as the base of the relief map, and to the same horizontal scale. This map need show contours only. Sheets of three-ply

board, of uniform thickness, and the same size as the map, are taken (one for each contour on the map), and covered with a thin white paper, well stuck on (use glue—best "Croid," thinned with an equal volume of water). On to the first of these boards is traced the lowest contour on the map—say 100-ft. contour. On the next board is traced

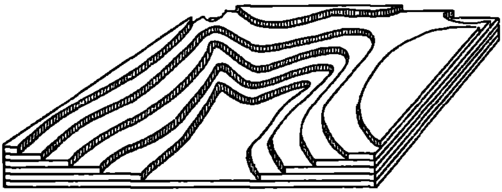


Fig. 164 (*a*).

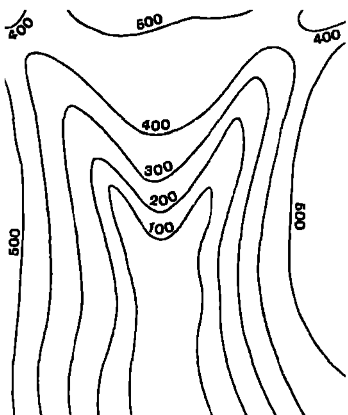


Fig. 164 (*b*).

the 100- and 200-ft. contours; on the next the 200- and 300-ft., and so on. The *lower* contour line on each board, *except* the first, is then cut out with a fretsaw (a treadle fretsaw is best and is well worth purchasing if much work in three-ply wood is done). The second board is then glued (use "Croid"!) on top of the first—the 100-ft. contour on the first enabling correct register to be made easily; the third, cut out to the 200-ft. contour, is then

glued to the second, which has a trace of the 200-ft. contour for registering, and so on. The result of this is a relief model rising by abrupt steps instead of gradually—as shown in Fig. 164, where *a* is a perspective view of a relief map at this stage, and *b* the contour map from which it was constructed. The "steps" are smoothed off with plasticine, and any necessary minor features can also be put in at this stage. The result is a relief map of the district required. Such a map is, however, unsatisfactory for any but purely temporary purposes. It is better to make a plaster cast of it. To do this, four upright pieces of board of suitable size are placed against

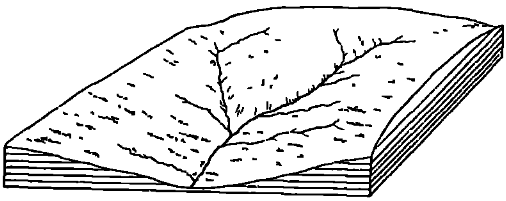


FIG. 165.

the sides of the relief map so as to make a box with the relief map at the bottom—the relief map and the insides of the boards forming the box having been given a thin layer of vaseline. The vaseline is best painted on the model with a smooth brush.

Some good plaster of Paris is next mixed with water to a thick creamy consistency, and poured into the box over the relief model till the highest parts are well covered, and the top of the plaster levelled off. When properly set, which will take some time, the plaster cast may be lifted off the relief model, the side boards having been taken off. This cast is a "negative." When thoroughly dry, it is brushed over with vaseline or oil, or coated with melted paraffin wax, and gently warmed (the object of the oil is to prevent the next cast from adhering). It is in turn surrounded by four boards to make a box, and the box again filled with plaster. This new cast, taken out

when it has properly set, is a positive, and can be coloured up in any desired manner, and, if necessary, geological sections can be shown on its vertical sides. A block diagram of the finished map is shown in Fig. 165. If the last process is carefully carried out and the negative has been well waxed, there is no limit to the number of positive casts which can be taken from it.

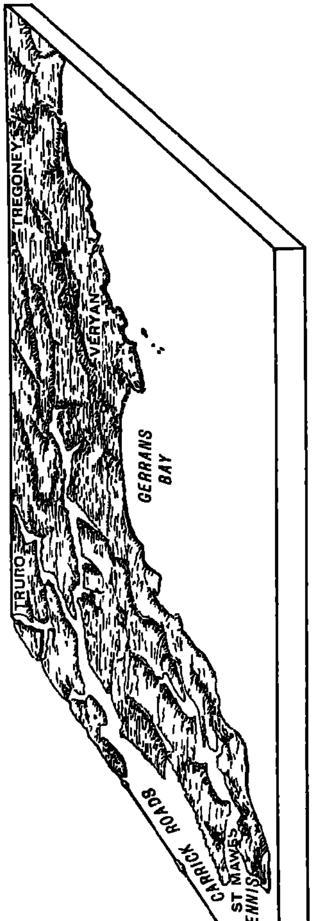


FIG. 166.—Part of the Falmouth Estuary. Showing the old Pliocene plain of marine denudation, dissected by an extensive river system, partially submerged to form an estuary.

The choice of vertical interval between the contours traced on to successive sheets of three-ply, and of thickness of three-ply, naturally depends on the vertical scale required. For country of low, or moderate, elevation, e.g. a portion of the Thames valley and neighbouring Chilterns, a reasonable representation is obtained by using three-ply boards about $\frac{3}{16}$ to $\frac{1}{4}$ in. thick for each 100-ft. contour.

Another method of construction is to rule across the map of the district to be modelled a number of parallel lines at equal intervals. Sections across the map along each of these lines are drawn on strips of cardboard, or

three-ply wood, with a suitable vertical scale, and the section cut out with knife or fretsaw. These sections are then fixed vertically at the same distance apart as the lines on the map, and the space in between filled with modelling clay, which is then brought up to the top of the sections. The sections thus act as a guide in modelling the relief in the clay. After the modelling is finished, the surface is oiled and waxed to prevent adherence of the plaster, and casts made as before.

There is no doubt that a relief model made as above has an appeal to the eye which is lacking in an ordinary diagram, and is a most valuable teaching adjunct. The making of the model, however, takes time, and its storage may also present difficulties where space is limited. In such cases, the next best substitute is a block diagram. Block diagrams are largely replacing the old line diagram in textbooks, and offer a much better means of conveying the required information. A block diagram is a perspective drawing, and shows, for instance, a tract of country in relief, and not in section, while sections can be shown on two sides of it. Many teachers, who have not had a training in drawing, are frightened at the idea of tackling perspective, but the difficulties are imaginary rather than real.

Figs. 164 (*a*) and 165 are examples of block diagrams, and can be drawn very easily with no knowledge of the laws of perspective by following very simple instructions for their geometrical construction. In a recently published book,[1] the authors describe very fully the manifold uses of block diagrams for geological teaching and demonstration, and the book is full of suggestions for the geographer also. The last two chapters give full instructions for the preparation of block diagrams and their use for geological demonstrations and lectures.

For showing a block diagram to a class, it may of course be drawn on a lantern slide—not too easy unless

[1] *Structure and Surface*, by C. Barrington Brown and F Debenham. London : Ed. Arnold, 1929.

the draughtsman is very handy with a really fine pen—or photographed and thus transferred to a slide (a better proceeding, since any imperfections of line are rendered less evident by reducing the original drawing when photographing it). An alternative to making a slide is to draw an enlarged diagram on cartridge paper and thus make a large wall diagram.

208. POYNTING PARALLEL PLATE MICROMETER

Birmingham, 1931

This is used in conjunction with an ordinary microscope or telescope for measurements such as the diameter of bore of a tube, extension of a wire, etc.

A piece of optically worked glass is held in the frame, O, fixed rigidly at right angles to a bar carrying a glass plate, G, with fine line scratched on it, and balanced by a small weight, W. This arm moves on axis, X, the line on G passing over a millimetre scale, S. The object to be measured is viewed through the glass block by means of a short focus telescope, T, adjustments being made so that one end of the image comes on the cross wire. The glass block is then turned until the other end of the image comes on the cross wire, the movement of G required to bring this about being noted. The scale, S, is calibrated by replacing the object being measured by a millimetre scale and taking readings of G when images

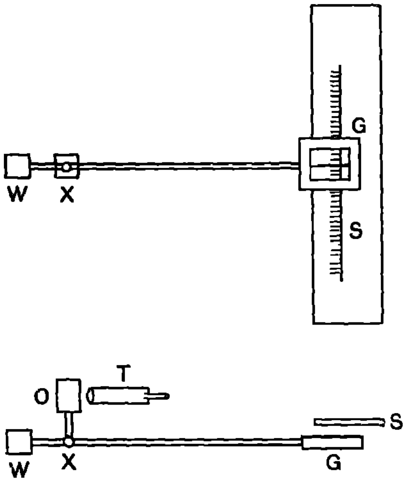


FIG. 167.

of successive divisions of the scale under observation are brought in turn on to the cross wire. The millimetre scale is calibrated against another millimetre scale, placed in the position of the object on the far side of O, readings being taken through a telescope, T.

The plates are 6 mm. thick, the pointer 25 cm. long, and about 100 millimetres on the scale, S, corresponds with 1 mm. on the object being measured.

NOTE ON THE ABOVE

V. T. Saunders

Consider a small object, OA, with O on the principal optical axis of the microscope and the block of glass normal to this axis, as shown in Fig. 168.

The rays show that the position of OA as viewed in the microscope appears to be IB.

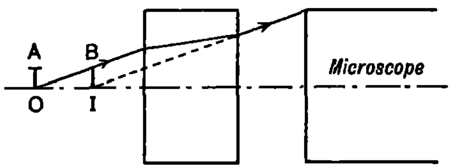


FIG. 168.

Now turn the block as shown in Fig. 169. The ray which leaves O and falls normally on the block, passes through without deviation and without side shift, but the ray which leaves O and coincides with the principal optical axis of the microscope is refracted as shown and suffers side shift. Thus rays falling on the microscope from O appear to diverge from I′, which is not on the principal optical axis; the object has apparently been side-shifted so that B′ appears to be on the principal optical axis of the instrument.

In the instrument described above, the block is turned by a long lever whose position is recorded on a scale. By putting a millimetre scale at OA, the positions of the lever

for millimetre intervals (i.e. OA) can be found, and so a calibration is obtained ; another way of expressing this

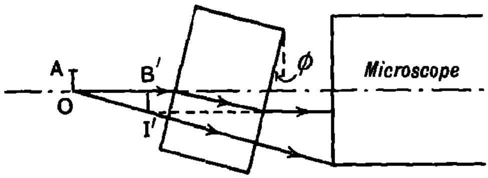


Fig. 169.

would be to say that by putting in known lengths at OA, a table of relative values of ϕ and OA is found.

209. A METALLIC ARC

Birmingham, 1931

Fig. 170 shows an arrangement for striking a metallic arc. The two wires, W, are fixed in a simple clip, C (an

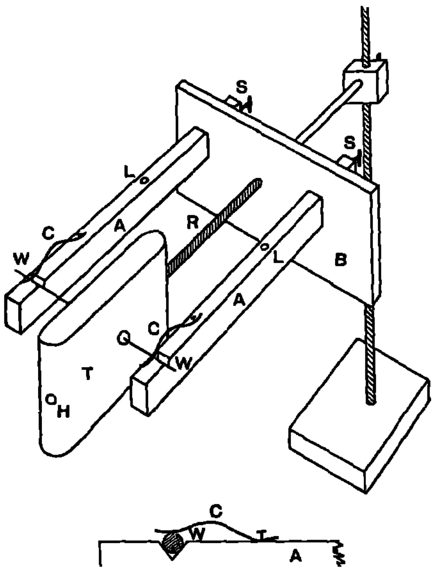


Fig. 170.

iron spring), on a brass arm, A. The two brass arms are held in an insulating block, B, on the far side of which

are binding screws, S, for connection to the mains. The arc is struck inside a metal shield of tin, T, which serves the double purpose of a shield and provides a cooling current by updraught.

The shield is held by a rod, R, passing into the insulating block, and is continued beyond this to a clamp on a standard, thus supporting the whole apparatus. A hole, H, in the front of the shield, enables the arc to be viewed by spectroscope. The arc is a horizontal one. Holes, L, are bored in the brass arms for cooling purposes.

The circuit is completed by passing through an ordinary heating element as resistance, mounted on a wooden base, the current being about 1 amp.

210. ELECTRICALLY HEATED CRUCIBLE FURNACE

Cambridge, 1923

Fig. 171 illustrates an electrically heated crucible furnace. The crucible, C, is placed on asbestos, within a silica lamp-glass, BB′. This cylinder stands on an asbestos card, A, and another card, A′, is placed above. Freshly ignited magnesia alba is placed below A and is packed round BB′, which is fitted with an external coil of nichrome ribbon (the temperature varies with the closeness of coiling). The whole of this may be conveniently contained in a "Bath Oliver" biscuit tin. It is important to secure non-conductivity of the magnesium oxide in the first instance. This is effected by strongly igniting the carbonate. In these circumstances, the crucible may be raised to 600° C. or 700° C., while the biscuit tin remains cold.

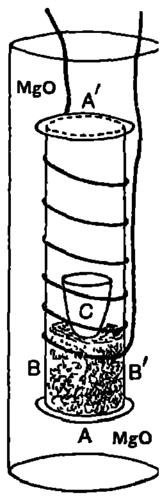


FIG. 171.

211. A LABORATORY BLOWER

Oxford, 1921

A large glass vessel is used as shown; the lower part contains water through which air bubbles in and replenishes the supply of compressed air in the upper part, which air produces a steady jet in the blow-pipe. The end of the tube leading in the water is bent upwards so that air is not sent up the water-escape tube. The maximum rate of flow depends, of course, on the efficiency of the filter pump.

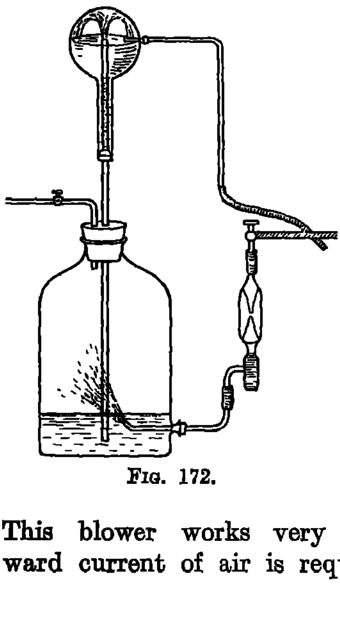


FIG. 172.

The following is a simpler arrangement.

The tail of a filter pump is fitted into the bung of a 4–5 litre aspirator, placed in a sink. The outflow of water from the aspirator is regulated by the tap at the bottom. This blower works very well where a gentle forward current of air is required.

212. SKEW PRISMS—METHOD OF GRINDING

Anonymous

Fig. 173 shows a skew prism which has an angle of about 8° at the apex, and the two faces are inclined at an angle of about 4° in a plane at right angles to the main angle of the wedge.

Wedges having plane faces from which the

prisms can be ground may be obtained from spectacle lens manufacturers. Two wedges are required. The skewed faces of the wedges are prepared for grinding in the following way. The two wedges are mounted side by side in plastic pitch (Fig. 174) contained in a cup made of a short piece of brass tubing of just sufficient diameter to permit of the mounting of the wedges for grinding. The ends of the tube are turned true. The correct location of the wedges is obtained by pressing down upon them a former (Fig. 175) until it makes contact with two flat pieces of steel (hack-saw blade) laid across the top of the cup clear of the wedges. When the pitch has set, the former is removed and the

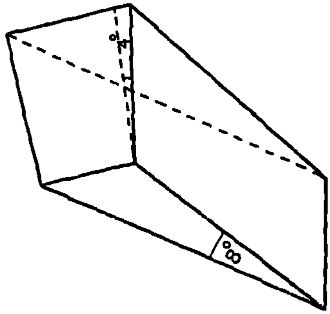


FIG. 173.

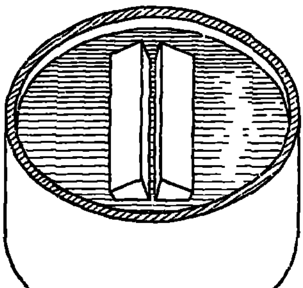


FIG. 174.

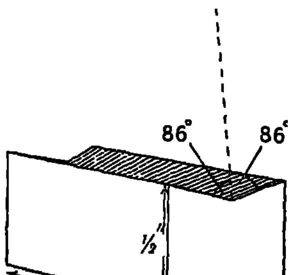


FIG. 175.

projecting parts of the wedges are ground off flat and polished. The pieces of steel must be sufficiently thick to allow the wedges to stand well clear of the pitch, so that at no time is pitch removed by the abrasive agent, otherwise difficulty will be experienced in polishing.

INDEX

Printed in Great Britain by
Hazell, Watson & Viney, Ltd., London and Aylesbury.